

Minnesota Intersection Control Evaluation Manual

2017



**Office of
Traffic,
Safety
& Technology**

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1.0 Introduction

1.1 Background

Engineers have an increasing number of options for intersection traffic control. Previously, the only solution to traffic delay and safety problems for at grade intersections was the installation of a traffic signal. Currently, other options including roundabouts, reduced conflict intersections, and higher capacity intersections are acceptable alternatives to transportation engineers. Previously, Signal Justification Reports (SJR) must have been completed before a new signal or significant modification of a signal could proceed. This process is described in the Minnesota Manual of Uniform Traffic Control Devices (MN MUTCD) from December 2011 and the former Minnesota Department of Transportation (MnDOT) Traffic Engineering Manual (TEM), which was updated in June 2015. The SJR is straight-forward and does not consider other options or alternatives. For this reason, the TEM has replaced it with the Intersection Control Evaluation process described in this document.

1.2 Definition

The Intersection Control Evaluation, or ICE, is a process that identifies the most appropriate intersection control type through a comprehensive analysis and documentation of the technical (safety, operational, other), economic (societal and agency cost), and political issues of viable alternatives.

1.3 Purpose

The goal of ICE is to select the optimal control for an intersection based on an objective analysis for the existing conditions and future needs.

In order to determine the optimal intersection control strategy, the overall design of the intersection must be considered. The flexibility of significant change in intersection design will largely be decided by the scope and location of the project. Some general objectives for good intersection design that should be considered are:

- ✓ Provide adequate sight distance
- ✓ Minimize points of conflict
- ✓ Simplify conflict areas
- ✓ Limit conflict frequency
- ✓ Minimize the severity of conflicts
- ✓ Minimize delay (for all users)
- ✓ Provide acceptable capacity
- ✓ Consider other transportation modes (pedestrian, transit, freight, bicycles etc.)

The purpose of the ICE report is to document all of the analysis (technical, economic, political, other) that went into determining the recommended alternative. Early decisions help limit scope creep. The ICE process helps collaborate with local agencies and considers all options on an equal basis.

Another purpose of the ICE Report is also for posterity. Many intersection decisions in the past have never been recorded or were poorly recorded. A well-documented ICE Report can help future transportation officials and engineers understand why certain decisions were made or influenced, and provide the data and context for that decision.

1.4 General Information

All intersection treatments must be considered as early in the project development process as feasible. This could occur during planning or corridor studies but no later than the scoping portion of an improvement project. A corridor analysis will be necessary for some projects. This will depend on the location of the intersection in relation to adjacent intersections and the respective traffic control of each.

An ICE is not required for intersections that are determined to need minimal traffic control (two way stop or no control). However, for any other type of control (All-way stop, roundabout, traffic signal, median treatment to reduce traffic movements, or other advanced traffic control systems) an ICE report is required for intersections on trunk highways. Preservation projects (e.g. signal rebuilds) will require minimal analysis and documentation. A memo/letter must be submitted for approval by the District Traffic Engineer. The document should state rationale for the work being done and why other types of traffic control are not being considered. This process is also recommended, but not required, for Counties and Cities.

Generally, intersection improvement projects are developed as a portion of a much larger project, or as a safety and/or capacity project at a specific location. For smaller projects, the proposed intersection traffic control modification is usually the major component of these types of projects and the ICE process will have a major impact in the development process. However, as part of a larger project, intersection control treatments may be a much smaller component and other project decisions will have more impact on how the ICE will proceed. It is important to emphasize that the ICE process occur as early in the project development process as practical so that the project proceeds smoothly.

ICE is conducted in two phases (refer to [Figure 1: The ICE Process](#)). If only one alternative is viable at the conclusion of Phase I, the evaluation is complete and it is unnecessary to proceed to Phase II. The report should document the Phase I analysis. For evaluations completed as a portion of a planning or corridor study, a Phase I analysis may be sufficient until specified projects are further defined. Depending on a project's complexity and scope, a detailed ICE report may be unnecessary. The District

Traffic Engineer in coordination with District management can reduce the amount of analysis and documentation if a preferred alternative is obvious. However, these decisions should be documented in the modified ICE report.

An ICE must be written under the supervision of a licensed Professional Engineer in the State of Minnesota and approved by the District Traffic Engineer before the preliminary plan is finalized. Each district can require additional review and approvals, if it is desired.

Included as a guide, *Table 1 – Potential Intersection Control by total Daily Entering Volume (ADT)* is used to assist in determining which intersection options should be evaluated based upon combined average daily traffic (ADT) volumes. The values are approximate and if an intersection is near a range boundary, consideration should be given to evaluating traffic control for both ranges. The ICE process is detail oriented and will have high resource demands. The process should only be done for intersections in which traffic control other than a two-way stop is required. As a guide, if the entering traffic for the minor leg of the intersection is less than 1,000 vehicles per day, an ICE may not be required.

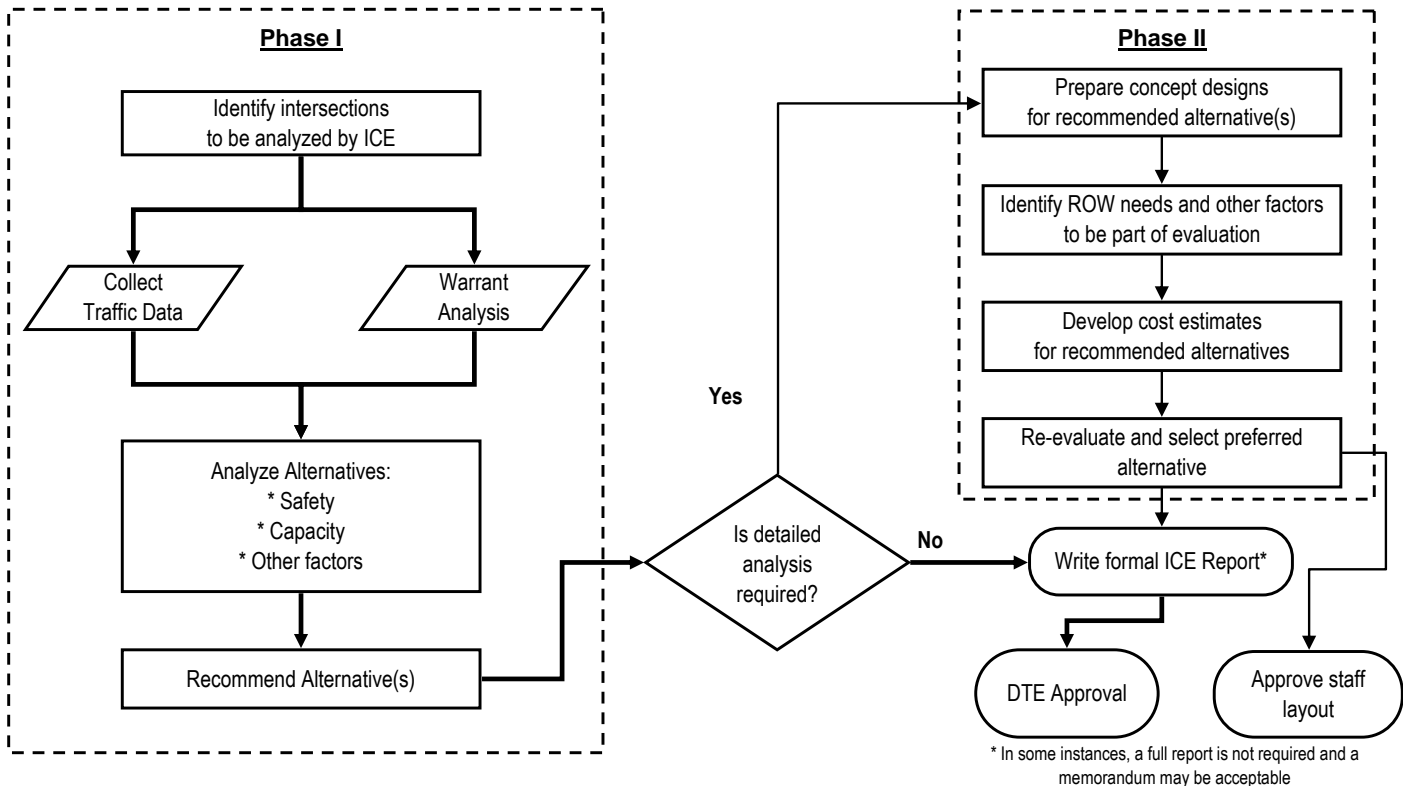
Table 1 – Potential Intersection Control by total Daily Entering Volume (ADT)

Approximate Combined ADT	Four Way Stop	Signal	Roundabout	Non-Traditional Intersection	Access Management Treatments	Grade Separation
7,500-10,000	X		X		X	
10,000-50,000	X	X	X	X	X	X
50,000-80,000		X	X	X	X	X
>80,000				X	X	X

2.0 The ICE Process

The process needed to complete an ICE is highly dependent on two factors. These factors will influence how much effort is involved in completing the study, who is involved in each stage of the study, and for what they are accountable. *Figure 1: The ICE Process* illustrates the ICE process.

Figure 1: The ICE Process



As shown in *Figure 1: The ICE Process*, the ICE is conducted in two phases. The first phase is usually done very early in the project development process, oftentimes before a project is programmed. This could occur during planning or corridor studies but no later than the scoping portion of an improvement project. The purpose of the first phase is to recommend one or more traffic control strategies for further analysis and development. Under normal circumstances, an ICE would be needed if a safety or capacity problem has been identified and that has an associated infrastructure improvement. An ICE is also required for a new intersection being constructed due to development or expansion of the highway system. The second phase, *Alternative Selection*, involves other functional units (Design, Land Management, etc) and parallels the process of developing an approved preliminary layout. Based on the considered factors, the recommended traffic control is determined in this phase.

Avoid overanalyzing a location. A simplified ICE written as a memorandum may be sufficient in some cases, with a short document discussing the engineering considerations and final decision. This can be helpful for tort liability and posterity. If a decision has been made or one traffic control type will be the choice, document the decision making process and include the decision in a short memo or basic report. The ICE can also be part of a larger Environmental Impact Study (EIS) or corridor study. It still may be necessary to gather traffic data, conduct a warrant analysis, and complete a safety and capacity analysis.

A decision may be reached after Phase 1. It may still be necessary to develop preliminary layouts, cost estimates and other project development tasks, but an ICE report can be completed at this time. However, if the project development process negates what has occurred in Phase 1, it will be necessary to revise the report.

For larger projects in areas where traffic volumes may increase on the local system as well as the arterial, careful consideration should be taken to determine if an ICE is necessary. Relying on future traffic projections, in which traffic volume warrants are barely met, should not be a requirement to perform an ICE. It is recommended to examine the expected traffic volumes 5 years into the future and assess whether the current traffic control is adequate. If it is not adequate an ICE should be considered at that time. Generally speaking, if warrants are unlikely to be met within a 5 year time frame, an ICE is unnecessary.

2.1 Phase 1 – Scoping

When the need for potential additional intersection control is determined, the project can originate within Mn/DOT or from an outside jurisdiction. If the project originates from an outside jurisdiction, that entity is responsible for conducting the ICE. When the needed ICE is on an intersection on the Trunk Highway Network, it is imperative that Mn/DOT District Traffic units be involved early in the process to ensure that the analysis will be accepted and approved. Within Mn/DOT, projects can originate within or outside of the District Traffic Engineering sections. The District Traffic Engineer will be responsible for facilitating the ICE development process on any project originating from their office. For all other projects, the District Traffic Engineer should be consulted early in the project development process to ensure that an ICE can be completed in a timely manner. For all ICEs completed by outside jurisdictions or consultants, the District Traffic Engineer is responsible for review and approval of all ICE Reports on State Trunk Highways.

2.1.1 Identify Intersections

Intersections which are a part of larger projects will probably require significant analysis and documentation. Coordination with District Traffic Engineering on these projects is important. Making decisions on traffic control earlier in the project development process will improve the quality of the design and minimize conflicts with stakeholders and public involvement.

Stand-alone intersections will require safety and capacity analyses as well as documentation of other impacts (cost, ROW, political concerns, etc). The amount of analysis will depend on each project's location and scope.

Generally, smaller intersections/project may require less analysis and less documentation. Preservation projects (e.g. signal rebuilds) will require minimal analysis and documentation. However, a memo/letter must be submitted for approval by the District Traffic Engineer. The document should state rationale for the work being done and why other types of traffic control are not being considered.

2.1.2 Collect Data

When starting the ICE, it is important to understand the data needs when starting the project. For completion of the report, the following data may be required. Some of these requirements can be waived or modified depending on the existing conditions and the available improvement alternatives. The District Traffic Engineer must be contacted to approve a change in requirements.

Traffic Volumes

- ✓ Hourly intersection approach counts (must be less than 2 years old) for 48 hours
- ✓ Turning movement counts for the AM and PM peak periods (3 hours each and less than 2 years old)
- ✓ Future intersection approach volumes (only needed if Warrant is unmet in existing time period)
- ✓ Future turning movement volumes for the AM and PM peak hours using pre- approved growth rates or future modeling parameters
- ✓ Pedestrian and bicycle volumes by approach, if applicable

Be sure to discuss with the District Traffic Engineer the traffic volume requirements for the particular study.

Crash Data

- ✓ Crash data for the last three full calendar years (Must be obtained from MnDOT, or other appropriate method). Additional years may be reviewed as well.
- ✓ Crash diagrams and summaries must be included in the report. Rationale for crash reductions based on each alternative must be documented. Crash listings should be included in an appendix.

Existing Geometrics

- ✓ The existing geometrics of the intersection being considered for improvement must be documented. It is preferable to provide a layout or graphical display of the intersections showing lane configurations with existing striping, lane widths, parking lanes, shoulders and/or curb treatments, medians, pedestrian and bicycle facilities, right of way limits and access driveways or adjacent roadways for all approaches. The posted speed limit and the current traffic control of each

roadway must also be shown or stated. Adjacent structures, overhead utilities, and vaults should also be outlined such as buildings, bridges, box culverts, power poles, etc.

- ✓ A larger scale map showing the intersection in relationship to parallel roadways and its relationship (including distances) to other access points along the corridor is also required.
- ✓ The locations of schools or other significant land uses, which may require more specialized treatment for pedestrians or vehicles, should be documented, if applicable.
- ✓ Geographic features must be shown if they will influence the selection of an alternative, such as severe grades, wetlands, parkland, etc.

Existing Capacity Analysis

A summary table of delays for all movements, approaches and overall intersection delay must be provided for AM and PM peak hours, both existing and future conditions, for each alternative analyzed. Software output should be included in an appendix. An electronic copy of the analysis is preferred.

Additional data may be necessary depending on the location and alternatives analyzed. These could include – community considerations (need for parking, sidewalks, bike lanes, etc); future development plans, which may influence access; types of vehicles intersecting roadway, if unusual; transit routes and frequency; compatibility with corridor plans or local transportation plans; Interregional Corridor performance and political considerations. In areas with heavy bicycle and/or pedestrian use, additional consideration should be used to ensure that they operate at a satisfactory level as well.

Proposed Geometrics/Traffic Control Alternatives

A layout or conceptual plan showing the proposed geometrics for the alternatives and recommended traffic control alternative must be included. An electronic copy of the design is preferred and may be required depending on the intersection alternatives. The plan should document all changes from the existing conditions.

2.1.3 Perform Warrant Analysis and Justification

In order for the engineer to determine if any traffic control is necessary at an intersection, data must be examined to determine if a “Warrant” is met for the particular intersection control alternative. Even if a “Warrant” is met, it may not be the correct action to take for a given situation. The engineer must determine if the treatment is “Justified.” The “Warrant” and “Justification” process is detailed below.

Warrants

The Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) contains warrants for All-way Stops and for Traffic Signals. Generally speaking, warrants are met if the amount of vehicular traffic, crashes, or pedestrians is significant enough to meet minimum levels. These levels are based on research, which documented the conditions where additional traffic control was considered.

Information needed to determine if a warrant is met is contained in the MN MUTCD and the Mn/DOT Traffic Engineering Manual.

A Mn/DOT District Traffic Engineer will interpret this information to determine which warrants apply to a given location. For example, refer to the Metro District's practice on traffic signal justification.

Traffic volumes must be obtained. For most cases, existing volumes are preferred. However, future anticipated volumes may be used if development is imminent, and a traffic engineering study has been completed. For new roadways, projections must be used. Confer with the District Traffic Engineer on which warrants will be allowed.

Warrants are commonly used to determine if either an all-way stop control or a traffic signal should be considered for a location. Roundabouts are considered to be warranted if traffic volumes meet the criteria for either all-way stops or traffic signals.

However, site-specific safety issues may warrant the installation of a traffic control device (e.g. a roundabout) where traffic volume warrants are not met. Special considerations to install a traffic control device should be taken at any intersection where "typical" warrants are not met but safety issues are present. The District Traffic Engineer must be consulted when these conditions are present for guidance on whether additional traffic control will be considered.

Justification

Even if an intersection meets a warrant for traffic control, that treatment may not be justified. The justification process requires engineering judgment. Whether an intersection justifies a particular type of intersection control is based upon a number of factors. The ICE report should document these factors to support the alternative or not. These factors should include, but are not limited to, the following:

- ✓ Existing safety and congestion issues
- ✓ Adopted plans for the roadway based on an adopted corridor study
- ✓ The spacing of nearby intersections or driveways and how they conform to adopted access management guidelines
- ✓ The environment in the corridor
- ✓ Future anticipated traffic volumes
- ✓ The distance to the nearest traffic controlled intersections
- ✓ The amount of turning traffic

- ✓ The breakdown and percentage of types of vehicles
- ✓ The amounts of non-motorized traffic
- ✓ Sight distance
- ✓ Available right of way
- ✓ Available funds for construction
- ✓ Support of the local users and local agencies

2.1.4 Metro Traffic Signal Justification

Mn/DOT Metro division has developed a justification process that is discussed in this section. This is to be used for all districts except when the particular district has a written methodology for signal justification.

The Metro process looks at particular warrants (not all eight) and mitigating factors. In addition, this process defines how to handle right turn movements at the intersection.

The full process can be found here explaining the warrants and needed documentation:

<http://dotapp7.dot.state.mn.us/edms/download?docId=700081>

If you have questions, please contact Program Support of MnDOT Metro District Traffic.

2.1.5 Analyze Alternatives

One of the most important aspects of this ICE process is the development and analyzation of several different alternatives. Using the criteria below, the engineer should find a preferred alternative, while also documenting and providing justification for the final decision.

2.1.5.1 Operations/ Delay Considerations

To evaluate the capacity and level of service of a particular intersection it is important to begin with the basic traffic data:

1. Existing AM and PM turning volumes
2. Design year AM and PM turning volumes (Compare design year flows with the existing flows and check out any anomalies. It is critical that the design year flows do not exceed the capacity of the surrounding network.)
3. Design vehicle
4. Base Plan with defined horizontal, vertical, and site constraints
5. Existing and design year pedestrian and bicycle volumes

For Phase I, Scoping, the capacity analysis will vary depending on the type of project. The primary goal in Phase I is to determine if the alternative will operate at an acceptable level of service. A secondary goal is to provide a comparison between the alternatives. Consult with the District's Traffic Engineering unit on acceptable procedures for this analysis. In all cases, analysis with acceptable capacity analysis software will meet this condition. Simplified methods are being explored and developed.

Year of Analysis

A 20 year projection is the default for this type of analysis. However, due to the variability in accuracy of traffic projections, shorter time frames should be strongly considered in many instances. If total development is expected to occur within 5 years, 5 years should be the target year for analysis. If the capacity analysis appears to highlight near failures within this timeframe, future projections should be analyzed.

Choice of Models

The use of traffic models and modeling software should be discussed with the district traffic engineer and/or staff before the beginning of projects. This can help to determine which software packages are appropriate as well as discussing current variables and defaults within a given model. All software uses and assumptions within a model and/or software should be documented within the ICE report.

2.1.5.2 Safety Considerations

Depending on the existing crash pattern at an intersection, different traffic control treatments will have predictable impacts on these patterns. For each alternative, an estimate of crash frequency should be completed. There are a number of methods for this task. The goal should be to determine the impacts of each alternative as accurately as feasible. The utilization of crash reduction factors, crash rates, comparisons to similar intersections, research and logic can all be used, but should be tempered by common sense. Consultation with the District Traffic Engineer is recommended on the most recent acceptable methods for a given treatment and location.

Existing crash records should be obtained and shown in the report.

For each alternative an estimate of future crashes should be obtained. At a minimum a crash rate comparison should be utilized to make sure that the proposed intersection type will operate in a safe manner. A table of average crash rates for each alternative has been developed and will be updated and revised periodically by the Safety Section in the Office of Traffic, Safety and Technology (OTST).

The Highway Safety Manual (HSM) provides crash prediction models that offers a more precise crash prediction based on the unique characteristics of the intersection (number of lanes, type of lanes, traffic volumes, etc.). It is highly recommended that the HSM be used to evaluate the safety merits of the intersection configuration under consideration.

The website <http://www.cmfclearinghouse.org/> can also provide relevant information about various traffic control devices and situations. The CMF Clearinghouse can be used with the HSM, or as an independent tool. Due to the variance in research and application, use of the CMF Clearinghouse should be done in collaboration with the District Traffic Engineer and/or OTST.

2.1.5.3 Pedestrian/ Bicycle Considerations

MnDOT strives to accommodate all transportation users including bicycles and pedestrians. . Depending on the volume of users and the sensitivity of the location, one alternative may be preferred to another. Additionally, if large numbers of non-motorized users are anticipated, they should be reflected in the capacity calculations. The highway capacity manual offers techniques to determine non-motorized traffic level and quality of service.

The study should address any of the above issues, if applicable, and indicate how they are considered in the final recommendation.

2.1.5.4 Other Considerations

Right of Way Impacts and Project Cost

Each alternative that is recommended to proceed to Phase II: Alternative Selection, will have concept drawings prepared for the purposes of determining right of way impacts as well as construction costs. The level of detail in the design will be determined by the project manager depending on the location, type of intersection alternative, and other issues. The goal of this step is to have reasonable assurance that all right of way impacts are determined and an accurate cost estimate is obtained.

Political/Public Considerations

A large factor in the decision of intersection control is driver expectancy. Each feasible alternative should be assessed for driver expectations and political viability. In Phase II, typically the local jurisdictions and other important stakeholders would be consulted to determine the acceptability of an alternative. If the result was negative, this alternative should be reconsidered from further consideration, especially if cost participation is required. During Phase II, the degree of public involvement in the discussion of alternatives must be determined by the project manager in consultation with local stakeholders and Mn/DOT functional units. In any event, stakeholders should be aware of the technical merits of each alternative.

Unconventional Intersection Geometry Evaluation

Conventional forms of traffic control are often less efficient at intersections with a difficult skew angle, significant offset, odd number of approaches, or close spacing to other intersections. Roundabouts may be better suited for such intersections, because they do not require complicated signing or signal phasing. Their ability to accommodate high turning volumes makes them especially effective at “Y” or “T” junctions. Roundabouts may also be useful in eliminating a pair of closely spaced intersections by combining them to form a multi-legged roundabout. Intersection sight distance for roundabouts are significantly less demanding than for other conventional intersection treatments.

Terrain

Traffic signals and roundabouts typically should be constructed on relatively level or non-rolling terrain. For traffic signals, the maximum approach grade will vary depending on the ability for approaching traffic to see the signal heads and the impact of the approach grade on the operations of the predominate vehicle type. For roundabouts, the maximum approach grade should be 4% within the required Stopping Sight Distance (SSD) of the yield line. Grades approaching these values and steeper terrain may require greater transitions to provide an appropriate level area or plateau for the intersection.

Adjacent Intersections and Coordinated Signal Systems

The spacing of intersections along a highway corridor should be consistent with the spacing of primary full-movement intersections as shown in the Mn/DOT Access Management Policy. District Traffic Engineering may allow intersection spacing exceptions for roundabouts based on justifiable merits on a case-by-case basis. Generally speaking, positioning a roundabout within a coordinated signal system or very near to an adjacent signal is not preferred. However, under some circumstances it may be an acceptable option. A comprehensive traffic analysis is needed to determine if it is appropriate to locate a roundabout within a coordinated signal network.

System Consistency

On Interregional Corridors (IRC) or other highways where a corridor study has previously been prepared, any alternative should address the impact on the Interregional Corridor performance, or should be compared to the recommendations of the corridor study. If the alternative adversely influences the performance of the IRC, or it is not consistent with the corridor study, justification for the alternative should be included.

2.1.6 Recommend Alternatives

Through the above analysis steps, a recommended alternative should be identified. The selection of the preferred alternative should be documented in the ICE report. Any conclusions specific to the selected alternative should be documented.

2.2 Phase 2 – Alternative Selection

For Phase II, Alternative Selection, a more rigorous capacity analysis should be completed. An analysis using acceptable software is required. Currently, RODEL is required for roundabout analysis. SYNCHRO and SIM-TRAFFIC is required for traffic signals and four way stops, and VISSIM may be required for multiple roundabouts, which are a portion of an overall system of traffic control. Due to the high rate of change in modeling software and technology, these requirements could change. Consult with District Traffic Engineering to insure which software is required or to be used.

The product of this analysis is a comparison of level of service, delay, and queue lengths for each alternative. This analysis should provide sufficient detail such that comparisons between alternatives can be made.

The results of the capacity analysis should be summarized in the report. Levels of Service, delay and maximum queue lengths should be reported for all approaches and/or traffic movements for all time periods and analysis years. It is recommended that an electronic copy of the initial conceptual design sketch and analysis be provided as documentation. ICE reports submitted without proper use of software will be rejected. When preparing the Phase II ICE, the following items listed below should be analyzed and documented in the report.

2.2.1 Prepare Conceptual Designs

Each alternative that is recommended to proceed to Phase II, Alternative Selection, will have concept drawings prepared for the purposes of determining right of way impacts as well as construction costs. The level of detail in the design will be determined by the project manager depending on the location, type of intersection alternative, and other issues. The goal of this step is to have reasonable assurance that all right of way impacts are determined and an accurate cost estimate is obtained.

2.2.2 Identify Right-of-Way Requirements

For each alternative, determine the Right-of-Way (ROW) needs for each alternative. This should include identification of environmentally sensitive lands (wetlands, historic property, potential contamination etc.), buildings needing to be acquired, federal or state lands, etc. The ROW acquisition may be an important consideration in the final selection of the preferred alternative.

2.2.3 Develop Cost Estimates

Determine the cost estimates for the selected alternative(s). The cost estimates should include as many known costs as possible. This includes, when possible; ROW costs, environmental abatement/mitigations, engineering/design costs, all construction costs and materials, risk considerations, and other relevant costs that will be needed to complete each alternative. Construction costs should be based off of the most recent data available, and should include factors for inflation or other potential cost increases between when the report is finished and the anticipated construction date.

2.2.4 Political/ Public Considerations

Similar to the Phase 1 of the ICE, the Phase II should discuss and evaluate the alternatives based on political and public considerations. Though this input should be considered, and documented, they should become a part of the discussion, and not what drives the final selection of intersection control. This input should be considered and documented, as part of the overall consideration of the traffic control to be implemented. This discussion should help in the consideration of the final intersection control but it may not be the biggest influence in the ultimate selection.

Stakeholder/ Partner Input

Since the ICE process will ultimately impact people's daily lives and likely use taxpayer money, it is important to have a stakeholder and public input become part of the ICE process. Cities and Counties who also own one or more legs of the intersection should be involved early on, especially if matching funds will be required.

Open House/ Public Comment

The "Open House" and public comment period is one of many ways to solicit feedback from a community regarding the possible choices and gather additional insight into public concerns and other

challenges. Though not required as part of the ICE process, larger and more controversial projects may need open houses and public engagement to make community officials more comfortable with the decision is made.

Early meetings have great potential to ascertain how the public may react to certain choices. One common idea is to bring several options that have been sketched out and still appear conceptual. This allows the officials to bring up multiple choices and have them as an equal alternative, and talk about the benefits/ drawbacks of each alternate. The public input can help to influence how much education and outreach may be needed as the project progresses.

These meetings and public comments should be incorporated into the final ICE document. This information can be helpful to future decision makers to help them understand why one intersection type was chosen over another.

2.2.5 Re-Evaluate Alternatives

As necessary, perform additional warrant, crash, and capacity analysis. Use this information, along with engineering judgment to compare and contrast the alternatives. The projects overall benefits (delay reductions, safety improvements, enhanced mobility) should be compared to the overall projects costs (right-of-way acquisition, wetland mitigations, design costs, construction costs, and any negative user impacts) to come up with a Benefit to Cost Ratio (B/C Ratio). Typically, the higher the number is, the better the alternative. However, this B/C must be weighed against limitations and overall project costs.

2.2.6 Select Preferred Alternative

With all the collected and analyzed information and data, including considerations of public and political commentary, the preferred alternative should be selected.

2.3 Approval and Report

During this stage, the formal report is created and final approvals are given.

2.3.1 Written Report

The purpose of the ICE report is to document all of the analysis (technical, financial, political) used to determine the recommended alternative.

Depending on the amount of analysis, an actual report may be unnecessary. For some projects, a memorandum may be all that is necessary (e.g., Traffic signal rebuild projects). In that case, a memorandum signed by the District Traffic Engineer with rationale that supports the decision is sufficient. Otherwise, the ICE report should follow the outline below and thoroughly document the process described previously.

Concurrence (Approval) Letter

The cover letter must be addressed to the District Traffic Engineer. It should include the name and address of the submitter, along with any specific information on expected project letting dates, funding sources, and linkages to other projects. The submitter should allow at least one month to obtain approval. Prior work and communication should help to ensure a smooth approval. This will not be needed if the report is done internally.

Cover Sheet

The cover sheet requests the approval of the District Traffic Engineer for the recommendations contained in the report. A signature block must be included with spaces for the report preparer (must be a registered engineer in the State of Minnesota), the engineering representative for the agency(s) with jurisdiction over the intersecting roadway, and the District Traffic Engineer.

Description of Location

The report must document the location of the project in relation to other roadways and include an accompanying map at a suitable scale.

Existing Conditions

The report must document the existing conditions of the roadway including existing traffic control, traffic volumes, crash data, roadway geometrics, conditions of the roadway, right of way limits, land use, etc. A graphic/layout should be used to display much of this information.

Future Conditions

The report must document future conditions (normally 20 years) based on anticipated development including traffic volumes, new or improved adjacent or parallel roadways, anticipated change in access (additions or removals), etc.

Analysis of Alternatives

The report must include a discussion of each alternative and why it is recommended or not. The report should document the following analyses for each alternative considered: warrant analyses, crash analyses, capacity analyses, right of way and construction cost impacts, political considerations, system consistency, and other considerations. Warrant analyses are usually done for existing conditions, however, in some cases future volumes (usually no more than 5 years) can be used if the submitter can document that development is imminent. Crash analysis is done comparing the existing crashes with those anticipated after the change in traffic control. It may be necessary to analyze crashes at nearby intersections if access is proposed to be restricted at the subject intersection. A capacity analysis for each alternative must be completed for existing conditions with and without the improvement. Additionally, a capacity analysis must be done for future conditions (usually 20 years into the future,

unless the improvement is anticipated to be temporary (in that case 5 years would be acceptable)). A discussion of the relative intersection delays for each alternative must be included. The Mn/DOT District Traffic Engineering unit should be contacted for acceptable software packages for capacity analysis for each alternative. Currently, RODEL is recommended for isolated roundabouts, VISSIM is recommended for roundabouts in very close proximity to other roundabouts or signalized intersections in addition to RODEL analyses, and SYNCHRO is recommended for traffic signals and all-way stops.

Recommended Alternative

The report must recommend an alternative based upon the alternative analysis and a discussion of the justification factors. The report must document the justification factors, which are appropriate for each alternative and come to a logical conclusion on which alternative is recommended.

Appendices

The report should include supporting data, diagrams and software reports that support the recommendations being made.

2.3.2 DTE Approval

An ICE must be written under the supervision of a licensed Professional Engineer in the State of Minnesota and approved by the District Traffic Engineer. Each district can require additional review and approvals, if it is desired.

2.3.3 Changing Traffic Control

If the ICE report is for an existing intersection, and the recommended alternative is to change the existing intersection control, caution should be exercised and well documented. This is especially true if the recommended traffic control is for less control. When making the transition, engineers should follow MUTCD guidelines, and engineering judgement to ensure a smooth and safe transition.

3.0 Types of Intersection Control

Engineers can select from a number of different alternatives for intersection control. Each type of control has advantages and disadvantages. Additionally, some types of control are not as common in Minnesota as traditional traffic control methods (roundabouts versus traffic signals). Each type of control should also be acceptable to the public, the local governmental unit, and the local road authority. Some types of traffic control with a few of their associated advantages and disadvantages are listed below. This is not intended to be an all-inclusive list of options. Depending on the existing circumstances and issues at a certain location, an entirely different or unique solution may be preferred and/or justified.

3.1 No Control

Intersections on low volume roads with other low volume roads may not need any control or signing. This is usually the case on many low speed residential roadways, or rural township intersections.

Advantages

- ✓ No signing to maintain and/or inventory

Disadvantages

- ✓ Right-of-Way may be unclear to approaching drivers

3.2 Thru-Yield

This type of intersection has one or more approaches controlled by a Yield Sign. Drivers on the approach with the yield sign are required to reduce their speed and concede the right-of-way to vehicles (and non-motorists) in the intersection, or approaching the intersection before they could safely enter.

Advantages

- ✓ Provides clear Right-of-Way to drivers on the approach leg
- ✓ Yield Signs can have higher compliance than STOP signs
- ✓ Provides no delay to thru drivers

Disadvantages

- ✓ Requires additional signing to maintain and inventory

3.3 Thru-Stop

This type of intersection has one or more approaches controlled by a STOP Sign. The leg with the lower volume and/or function is typically the leg required to stop. Drivers on the approach with the STOP sign are required to reduce their speed, stop, and concede the right-of-way to vehicles (and non-motorists) in the intersection, or approaching the intersection before they could safely enter.

Advantages

- ✓ Provides clear Right-of-Way to drivers on the approach leg
- ✓ Provides no delay to thru drivers

Disadvantages

- ✓ Unwarranted or unneeded stop signs may have poor compliance

3.4 Multi/ All-Way Stop

Multi-way stop control can be useful as a safety measure at intersections if certain traffic conditions exist. Safety concerns associated with multi-way stops include pedestrians, bicyclists, and all road users expecting other road users to stop. Multi-way stop control is used where the volume of traffic on the intersecting roads is approximately equal.

The restrictions on the use of STOP signs described in Section 2B.4 and 2B.5 of the 2011 Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) also apply to multi-way stop applications.

The decision to install multi-way stop control should be based on an engineering study (such as an ICE). The following criteria should be considered in the engineering study for a multi-way STOP sign installation, as outlined in the 2011 MN MUTCD Chapter 2B.7

Advantages

- ✓ Provide for orderly flow of traffic
- ✓ Reduce the severity and frequency of right angle and left turn crashes
- ✓ Relatively inexpensive and quick to implement

Disadvantages

- ✓ Some types of crashes may increase
- ✓ Limited to lower volume intersections
- ✓ Increases delay to all legs of the intersection
- ✓ Works best with single lane approaches
- ✓ Total intersection capacity is limited
- ✓ Providing for U turns can be difficult and may be prohibited

Information in this section was taken from the 2011 MN MUTCD.

3.5 Traffic Signal

A traffic control signal (traffic signal) shall be defined as any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed.

Traffic signals are a common form of traffic control used by State and local agencies to address roadway operations. They allow the shared use of road space by separating conflicting movements in time and allocating delay. They can also be used to enhance the mobility of movement along a major arterial.

In some cases, the dual objectives of mobility and safety conflict. To meet increasing and changing demands, one element may need to be sacrificed to some degree to achieve improvements in another.

In all cases, it is important to understand the degree to which traffic signals are providing mobility and safety for each mode of transportation. An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location. The investigation of the need for a traffic control signal shall include an analysis of the applicable factors contained in the following traffic signal warrants and other factors related to existing operation and safety at the study location. These warrants and discussion can be found in Chapter 4 and specifically Chapter 4.C of the Minnesota MUTCD (Mn MUTCD, December 2011). Additional information is also in the Minnesota TEM in Chapter 9. The current nine warrants are:

- ✓ Warrant 1, Eight-Hour Vehicular Volume.
- ✓ Warrant 2, Four-Hour Vehicular Volume.
- ✓ Warrant 3, Peak Hour.
- ✓ Warrant 4, Pedestrian Volume.
- ✓ Warrant 5, School Crossing.
- ✓ Warrant 6, Coordinated Signal System.
- ✓ Warrant 7, Crash Experience.
- ✓ Warrant 8, Roadway Network.
- ✓ Warrant 9, Intersection Near a Grade Crossing

The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal (see Metro Traffic Signal Justification 2.1.4. A traffic control signal should not be installed unless an engineering study indicates that installing a traffic control signal will improve the

overall safety and/or operation of the intersection. A traffic control signal should not be installed if it will seriously disrupt progressive traffic flow.

As with the installation of a traffic control signal, a comprehensive investigation and engineering study shall be completed to determine whether to remove or to retain a traffic control signal. The failure to satisfy any warrant is not in itself justification for removal of a signal. Information should be obtained by means of engineering studies and compared with the requirements in “User Guide For Removal Of Not Needed Traffic Signals”, Implementation Package, FHWA-IP-80-12, November, 1980.

Other resources for traffic signal removal include:

1. MnDOT’s “Traffic Control Signal Design Manual”
2. Minnesota Traffic Engineering Manual, 9-5.02.05
3. MN MUTCD Chapter 4B.2

The engineering study (or ICE) should indicate whether the removal or retention of a traffic control signal will improve the overall safety and/or operation of the intersection.

Advantages

When properly used, traffic control signals are valuable devices for the control of vehicular and pedestrian traffic. They assign the right-of-way to the various traffic movements and thereby profoundly influence traffic flow. Traffic control signals that are properly designed, located, operated, and maintained will have one or more of the following advantages:

- ✓ Provide for orderly flow of traffic
- ✓ Works extremely well in coordinated systems
- ✓ At times it may reduce the severity and frequency of right angle and left turn crashes
- ✓ Excellent for emergency vehicles if pre-emption devices are installed
- ✓ Interrupt heavy traffic to allow non-motorized traffic to cross
- ✓ Delay can be minimized for specific traffic movements

Disadvantages

Traffic control signals are often considered a panacea for all traffic problems at intersections. This belief has led to traffic control signals being installed at many locations where they are not needed, adversely affecting the safety and efficiency of vehicular, bicycle, and pedestrian traffic. Traffic control signals, even when justified by traffic and roadway conditions, can be ill-designed, ineffectively placed, improperly operated, or poorly maintained. Improper or unjustified traffic control signals can result in one or more of the following disadvantages:

- ✓ Significant increase in crash frequency (e.g. rear end collisions)
- ✓ Costly to install
- ✓ Requires considerable maintenance
- ✓ May increase vehicular delay and traffic queues (primarily mainline traffic)
- ✓ Higher traffic volumes increase size of intersection and number of lanes prior to intersection
- ✓ May require additional right of way beyond intersection for additional turn lanes
- ✓ Decreased efficiency with high left turning volumes
- ✓ Providing for U turns can be difficult and may be prohibited

Information in this section was taken from the MUTCD, 2011 and Signalized Intersections: Informational Guide (FHWA, July 2013).

3.6 Roundabouts

Roundabouts are circular intersections with specific design and traffic control features. These features include field control of all entering traffic, channelized approaches, and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 50 km/h (30 mph). *Figure 2: Roundabout Diagram with Key Elements* illustrates a typical roundabout with four legs and the key elements.

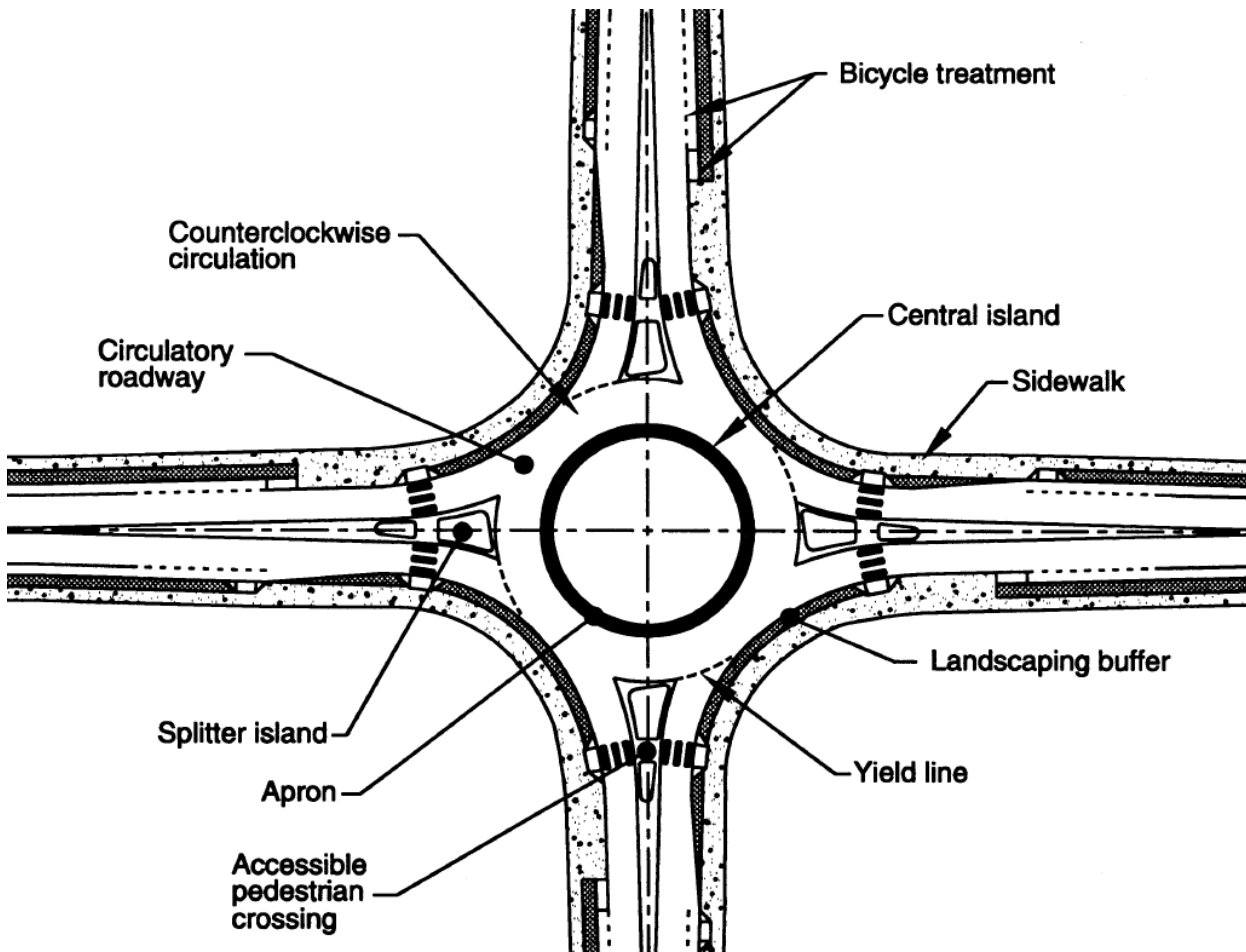


Figure 3: Roundabout Diagram with Key Elements

Roundabouts have several advantages over traditional intersections. Roundabouts are typically one of the safest intersection types, having low crash rates, low frequency, and low severity crashes. In addition, roundabouts typically have very high capacity with little delayed when compared to an intersection with a similar number of lanes and signalization.

Roundabouts have been categorized according to size and environment to facilitate discussion of specific performance or design issues. There are six basic categories based on environment, number of lanes, and size:

- ✓ Mini-roundabouts
- ✓ Urban compact roundabouts
- ✓ Urban single-lane roundabouts
- ✓ Urban double-lane roundabouts
- ✓ Rural single-lane roundabouts
- ✓ Rural double-lane roundabouts

Table 2 - Basic Design Characteristics for Roundabout Categories summarizes and compares some fundamental design and operational elements for each of the six roundabout categories.

Table 2 - Basic Design Characteristics for Roundabout Categories

Design Element	Mini-Roundabout	Urban Compact	Urban Single-Lane	Urban Double-Lane	Rural Single-Lane	Rural Double-Lane
Recommended maximum entry design speed	25 km/h (15 mph)	25 km/h (15 mph)	35 km/h (20 mph)	40 km/h (25 mph)	40 km/h (25 mph)	50 km/h (30 mph)
Maximum number of entering lanes per approach	1	1	1	2	1	2
Typical inscribed circle diameter ¹	13 m to 25 m (45 ft to 80 ft)	25 to 30 m (80 to 100 ft)	30 to 40 m (100 to 130 ft)	45 to 55 m (150 to 180 ft)	35 to 40 m (115 to 130 ft)	55 to 60 m (180 to 200 ft)
Splitter island treatment	Raised if possible, crosswalk cut if raised	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised, with crosswalk cut	Raised and extended, with crosswalk cut	Raised and extended, with crosswalk cut
Typical daily service volumes on 4-leg roundabout (veh/day)	10,000	15,000	20,000	Refer to Chapter 4 procedures	20,000	Refer to Chapter 4 procedures

1. Assumes 90-degree entries and no more than four legs.

When selecting roundabouts, engineers should anticipate the needs of pedestrians, bicyclists, and large vehicles. Whenever a raised splitter island is provided, there should also be an at-grade pedestrian refuge. In this case, the pedestrian crossing facilitates two separate moves: curb-to-island and island-to-curb. The exit crossing will typically require more vigilance from the pedestrian and motorist than the entry crossing. Further, it is recommended that all urban crosswalks be marked. Under all urban design categories, special attention to design elements should be given to assist pedestrian users who are visually impaired or blind. These users typically attempt to maintain their approach alignment to continue across a street in the crosswalk, since the crosswalk is often a direct

extension of the sidewalk. A roundabout requires deviation from that alignment, and attention needs to be given to providing appropriate informational cues to pedestrians regarding the location of the sidewalk and the crosswalk, even at mini-roundabouts. Appropriate landscaping is one method of providing some information. Another is to align the crosswalk ramps perpendicular to the pedestrian's line of travel through the pedestrian refuge.

Advantages

- ✓ Provide for orderly flow of traffic
- ✓ Works extremely well in series (multiple roundabouts along corridors)
- ✓ Minimizes the severity and frequency of most crash types
- ✓ Provide the least amount of vehicular conflict points
- ✓ Lifecycle costs are less than traffic signals
- ✓ Width of approach legs can be minimized
- ✓ Comparable if not greater capacity than other alternatives
- ✓ U turns are easily handled
- ✓ Works well with high percentages of left turning traffic
- ✓ Works well at diamond interchange termini
- ✓ Typically less delay than other types of intersection control
- ✓ Handles multiple legs and skewed intersections better than other types of intersection control
- ✓ Excellent for access controlled corridors or with areas using right-in/right-out accesses

Disadvantages

- ✓ May need additional right of way at intersection
- ✓ Operates poorly if the geometrics are not designed properly
- ✓ Typically requires additional features such as landscaping, lighting, and truck aprons
- ✓ Typically requires more initial design effort than other intersection types
- ✓ May operate poorly if intersection is near signalized or all-way stop controlled intersections
- ✓ Works best with single lane approaches
- ✓ May operate poorly if traffic volumes are greatly unbalanced
- ✓ May hinder efficient traffic flow in a coordinated signal system
- ✓ May be infeasible in areas of steep terrain where grades at the intersection cannot maintain less than 4% slope at the approaches and exits
- ✓ May not function properly if located on the crest of a vertical curve

Information in this section was taken from Roundabouts: An Informational Guide, Second Edition (FHWA, 2010)/ NCHRP 672.

3.7 Reduced Conflict Intersections

Unsignalized

The Reduced Conflict Intersection (RCI) intersection (also known as a J-Turn, Superstreet, Restricted Crossing U-Turn, and/or $\frac{3}{4}$ Intersection) is primarily to improve safety. It is an intersection type that is used on high-volume divided highways. Though not exclusive, it has been implemented mostly on rural, high-speed, high volume expressways.

With an RCI, crossroad drivers (minor through and minor left turners) cannot proceed straight through the intersection. The RCI, shown in [Figure 4: The Reduced Conflict Intersection \(Unsignalized\)](#), replaces these maneuvers with an indirect maneuver, and these are accomplished with a U-turn in the median. Eliminating the crossing maneuver eliminates the most frequent and most severe crashes at these intersections: the right angle crash.

A through movement is accomplished by turning right onto the major road, u-turning through the crossover, and turning right again back onto the minor road.

A left turning movement is accomplished by turning right onto the major road, and u-turning through the crossover.

All movements from the major road, including left turns, are direct.

Though research is constantly updating these distances, crossovers should be located approximately 600 ft from the main intersection. A semi-trailer combination design vehicle would need a median width of 60 ft to accommodate a U-turn. Additional right-of-way should not be needed where the major streets already have a wide median.

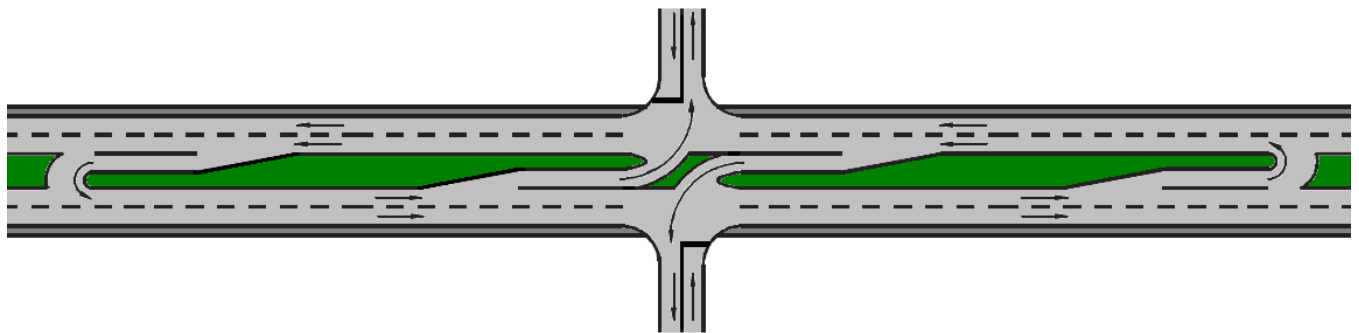


Figure 4: The Reduced Conflict Intersection (Unsignalized)

To date, RCI's have only been built on multi-lane expressways. However, it is conceivable that the intersection would work on a two-lane highway. During a Road Safety Audit of US 12, it was found many intersections had significant major road volumes, and minor roads with low volume. Through

some discussion, a single lane RCI became a potential option. Though not constructed, nor being considered, it could be an option at other intersection. See [Figure 5: A single lane Reduced Conflict Intersection](#).

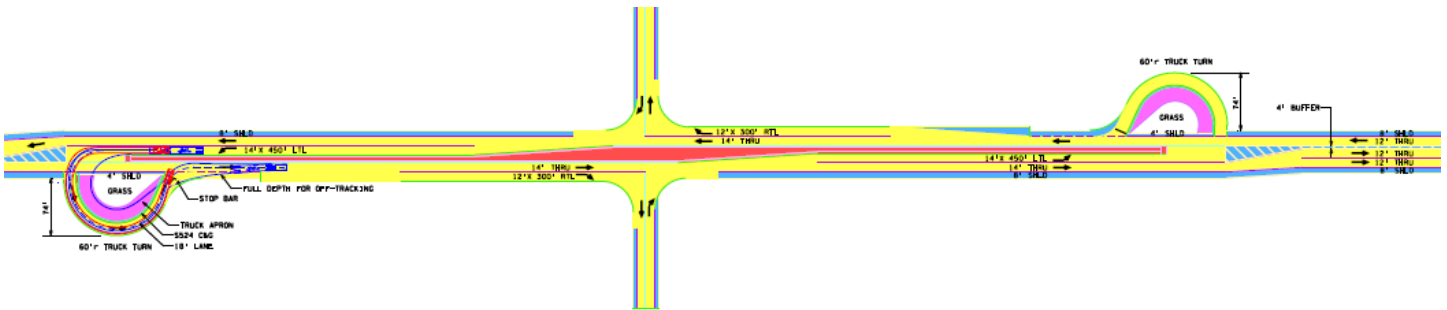


Figure 5: A single lane Reduced Conflict Intersection

Signalized

A signalized RCI has similar geometrics to the unsignalized RCI. The primary benefits of having a signalized intersection are two-fold; operations and safety. Since minor street through and left turning maneuvers are eliminated (and replaced with U-turns), traffic operations at the signal can be reduced from eight phases to two phases. With this reduction, significant green time can be shifted to the primary movements, while also reducing the total lost time at the signal due to switching of the phasing. In some scenarios, delay on the minor roads can be reduced to less than the current existing eight phase signal, especially where one road has significantly larger traffic volumes. The total delay at the intersection can be improved dramatically. The other benefit is in safety. The reduction of red light time, and the elimination of the crossing maneuver, crashes such as rear-end and right-angle can be greatly reduced.

The operations of the signalized RCI are greatly simplified. A two-phase traffic signal is all that is needed: two signal systems the main intersection. Because no minor street through or left-turn movements are allowed, these two signals can operate independently with different signal cycle lengths, if desired. In addition, a traffic signal may be needed at each of the upstream median crossover locations; these signals would also have only two phases. Because the two halves of the intersection operate independently, it is possible to achieve a maximum amount of traffic progression in both directions along the major street. This can be ideal for corridors with heavy commuter traffic (green time favored in the morning for inbound traffic, and switched for afternoon outbound traffic). This design is appropriate in situations where there are high through volumes on the major road but only relatively low volumes of traffic on the cross road.

There are fewer conflict points with this intersection design than with conventional intersections. Though this design may cause confusion for pedestrians, there is less opportunity for conflicts with vehicles. The crossing is a two-stage process.

It is important to mention the unsignalized and signalized RCI's can coexist on a corridor and operate well.

Advantages

- ✓ Major safety improvements, especially for severe right-angle crashes.
- ✓ Fewer conflict points.
- ✓ Improved delay for major street movements.
- ✓ Potential improvement for delay on minor streets, depending on location and time of day.
- ✓ Significant savings on cost and time to implement versus a traditional interchange.
- ✓ Signalized corridors can have excellent progression for an entire corridor.

Disadvantages

- ✓ Longer travel distance and time for minor street movements.
- ✓ Two-stage pedestrian crossing.
- ✓ Potential pedestrian way-finding challenges.
- ✓ Wide median required.
- ✓ May result in restrictions to access.
- ✓ Potential for driver and pedestrian confusion.
- ✓ Difficult concept for the public to accept as a reasonable solution

Information in this section was taken from Restricted Crossing U-Turns: Informational Guide (FHWA, 2014).

3.8 Median U-Turns

Median U-turns are a variant of the Reduced Conflict Intersection. In median u-turns, crossovers/u-turns are used to eliminate left turns at intersections and move them to median u-turns beyond the intersection. For median U-turn crossovers located on the major road, drivers turn left off the major road by passing through the intersection, making a U-turn at the crossover, and turning right at the cross road. Drivers wishing to turn left onto the major road from the cross street turn right onto the major road and make a U-turn at the crossover. *Figure 6: A Median U-Turn Intersection* illustrates a median U-turn configuration.

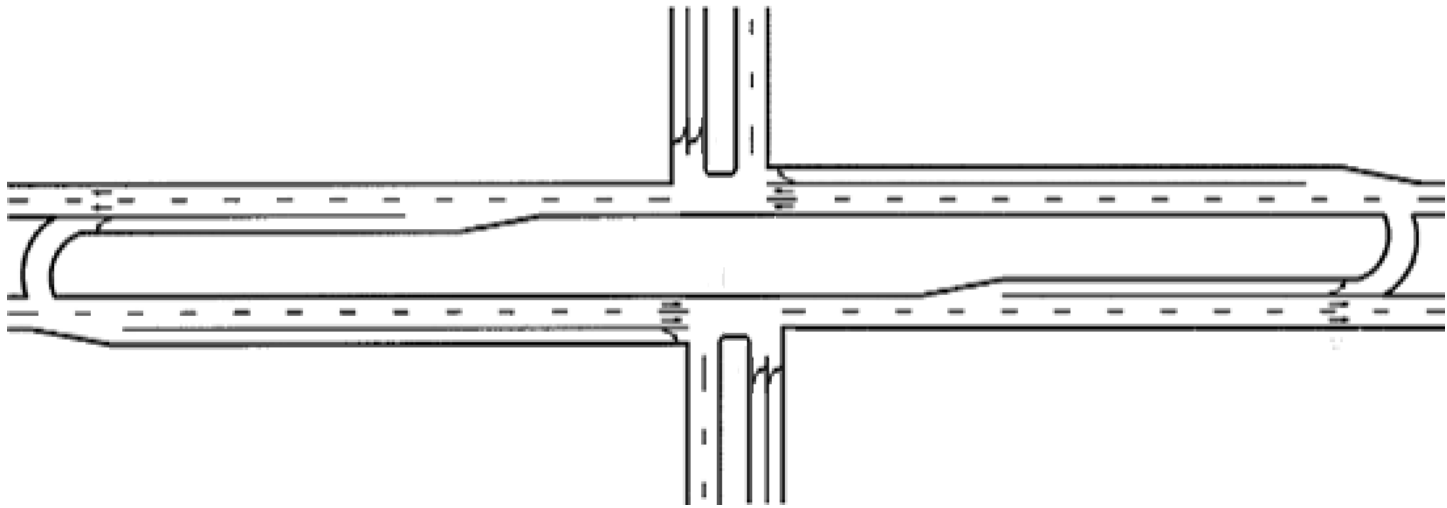


Figure 6: A Median U-Turn Intersection

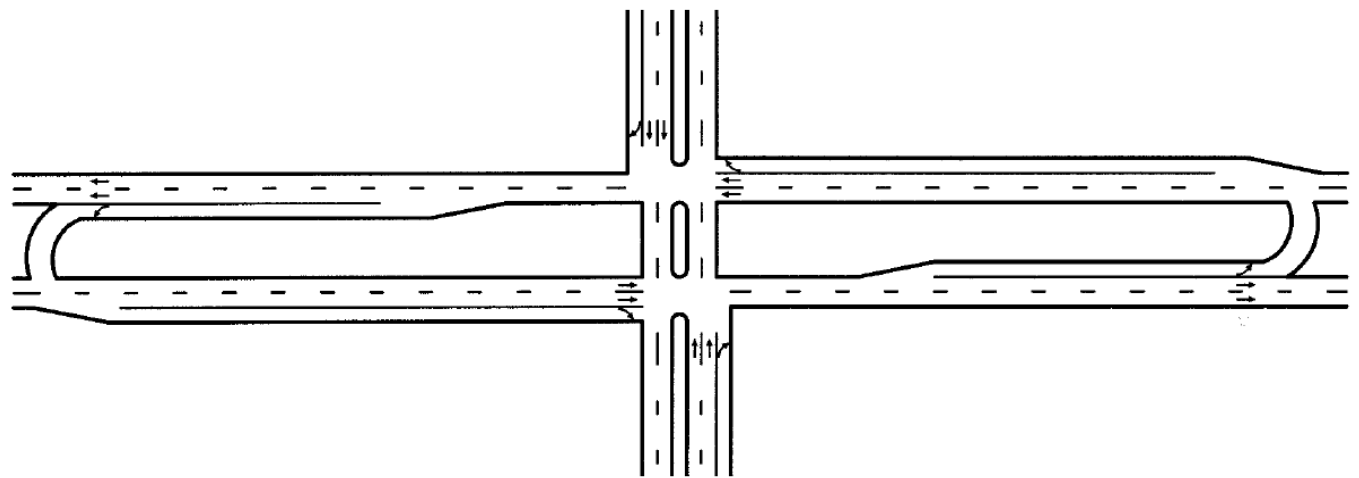


Figure 7: A Median U-Turn intersection with through traffic maintained. Also known as a Michigan Left.

When the intersection is signalized, and the minor road through traffic is allowed, this is often called a Michigan Left. Minor road traffic attempting to turn left is not allowed, and those attempting to complete a left are often met with a considerable amount of traffic that they need to yield to.

Figure 7: A Median U-Turn intersection with through traffic maintained. Also known as a Michigan Left. illustrates the geometric layout at such an intersection with a wide median.

Figure 7: A Median U-Turn intersection with through traffic maintained. Also known as a Michigan Left. illustrates the geometric layout at such an intersection with a narrow median.

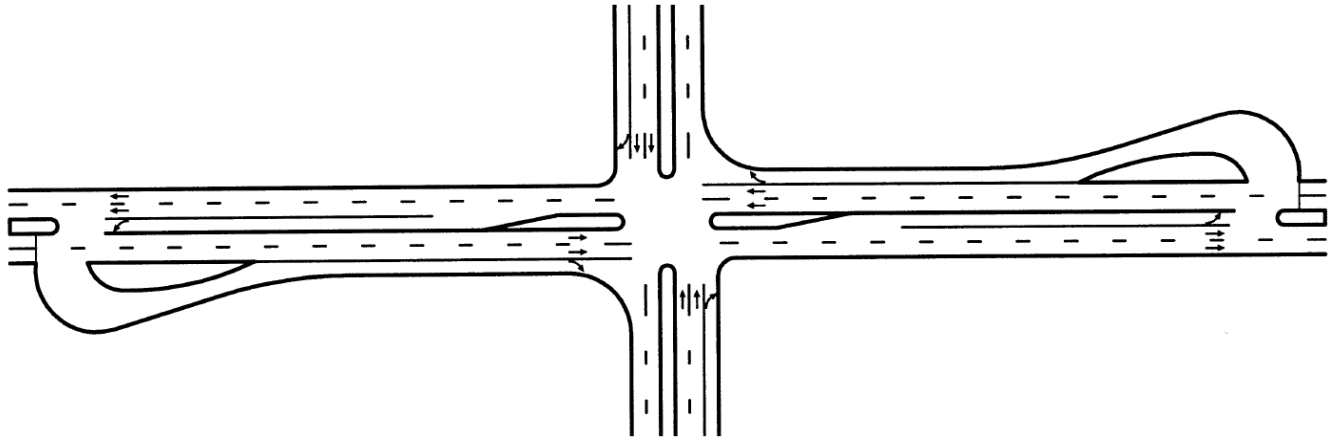


Figure 8: A Michigan Left/Median U-turn at an intersection with limited cross median spacing.

Advantages

- ✓ Potential major reduction in left-turn collisions
- ✓ Potential reduction merging/diverging collisions.
- ✓ Potential reduction in overall travel time.
- ✓ Reduction in stops for mainline through movements.
- ✓ Number of conflicting movements at intersections is reduced.

Disadvantages

- ✓ Increased pedestrian crossing distance.
- ✓ Turning paths of the median u-turn may encroach on bike lanes.
- ✓ May be additional right-of-way needs depending on the width of existing median.
- ✓ Access may need to be restricted within the influence of the median u-turn locations.
- ✓ Enforcement and education may be necessary to prevent illegal left turns at the main intersections.
- ✓ Difficult concept for the public to accept as a reasonable solution.

3.9 Bowtie Intersection

Another variation of the median u-turn/Michigan left is a combination of intersections. Roundabouts on the cross-street are used to accommodate arterial and cross-street left turns. Arterial left turns turn right at the cross-street and use the roundabout to "double back" thru the main intersection. Left turns at the main intersection are prohibited, eliminating the left turn bays and reducing right-of-way requirements. The main intersection operates under a simple two-phase signal control. *Figure 9: A bowtie intersection* illustrates this intersection.

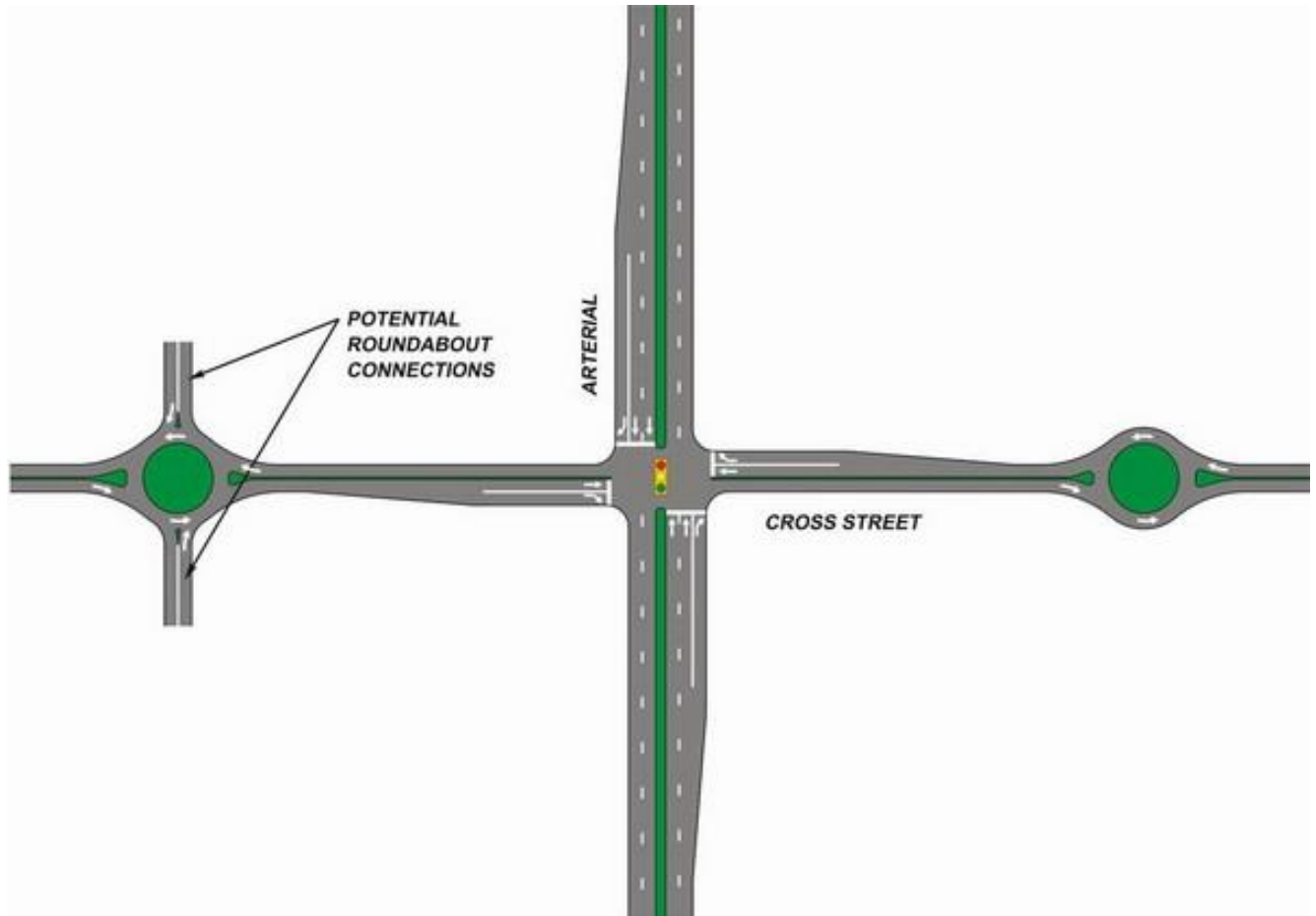


Figure 9: A bowtie intersection

Studies using microsimulation analysis have found the Bowtie Intersection can have modest travel timesaving over conventional intersections for some volume combinations. Several state agencies are experimenting with roundabouts on cross streets, several which include turning prohibitions. At the time of this document, no bowtie intersections have been built in the United States.

Advantages

- ✓ Potential major reduction in left-turn collisions
- ✓ Signal operations simplified to two phases.
- ✓ Potential reduction in overall intersection delay.
- ✓ Reduction in stops for mainline through movements.
- ✓ Number of conflicting movements at intersections is reduced.

Disadvantages

- ✓ Greater distance and time for all of the left turner
- ✓ Potential Driver Confusion
- ✓ May be additional right-of-way needs at roundabout locations
- ✓ Access may need to be restricted within the influence of the bowties.
- ✓ Enforcement and education may be necessary to prevent illegal left turns at the main intersections.
- ✓ Difficult concept for the public to accept as a reasonable solution.

3.10 Continuous Green T-Intersection

The Continuous Green T, as shown in [Figure 10: Channelized and non-channelized Continuous Green T-Intersections](#), can only be used at T-intersections. The design provides free-flow operations in one direction on the arterial and can reduce the number of approach movements that need to stop to three phases by using free-flow right turn lanes on the arterial and cross streets and acceleration/merge lanes for left turn movements from the cross street.

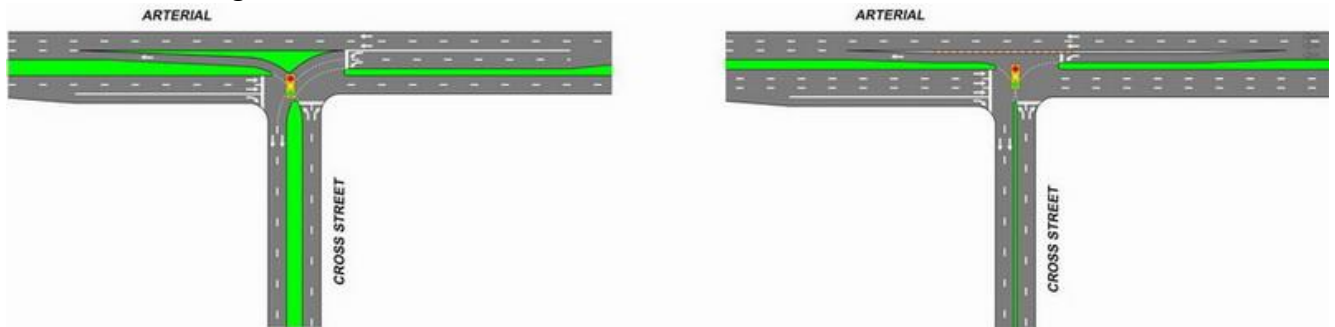


Figure 10: Channelized and non-channelized Continuous Green T-Intersections

While most unconventional designs can be evaluated as alternatives at both three- and four-leg intersection approaches, the Continuous Green T-intersection design can only be implemented at T-intersections. Minnesota has implemented Continuous Green T-Intersections, most notably at TH 12 and TH 25 near Montrose. See [Figure 11: Continuous Green T-Intersection near Montrose, MN.](#) and [Figure 12: Conceptual Layout of the Continuous Green T-Intersection near Montrose, MN.](#) for more information.



Figure 11: Continuous Green T-Intersection near Montrose, MN.

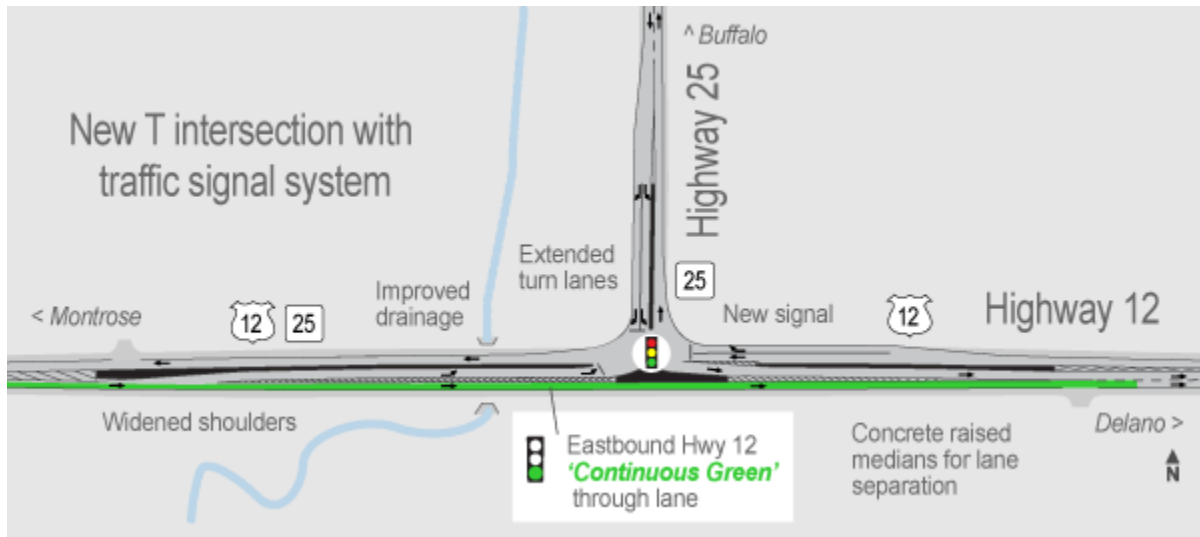


Figure 12: Conceptual Layout of the Continuous Green T-Intersection near Montrose, MN.

Advantages

- ✓ Signal operations simplified to three phases.
- ✓ Potential reduction in left-turn collisions
- ✓ Potential reduction in overall intersection delay, especially for one direction of arterial movements.
- ✓ Reduction in stops for mainline through movements.

Disadvantages

- ✓ Only available at 3 legged/T intersections.
- ✓ Potential Driver Confusion
- ✓ Potential additional right-of-way needs
- ✓ Education may be necessary

3.11 Continuous Flow Intersections

Continuous flow intersections (CFI), both full and partial, have recently been constructed in a small number of locations in the United States. CFI are also sometimes referred to as crossover-displaced left-turn (XDLT) intersections.

A CFI removes the conflict between left-turning vehicles and oncoming traffic by introducing a left-turn bay placed to the left of oncoming traffic. Vehicles access the left-turn bay at a midblock signalized intersection on the approach where continuous flow is desired. *Figure 13: A Continuous Flow Intersection* shows the design of a CFI with crossover displaced left turns. The left turns potentially stop three times: once at the midblock signal on approach, once at the main intersection, and once at the midblock signal on departure. However, careful signal coordination can minimize the number of stops. Note that this section describes an at-grade CFI; a grade-separated version of the CFI was patented (U.S. Patent No. 5,049,000), but the patent expired in 2003.

The complete CFI design operates as a set of two-phase signals. As part of the first phase, traffic is permitted to enter the left-turn bay by crossing the oncoming traffic lanes during the signal phase serving cross-street traffic. The second signal phase, which serves through traffic, also serves the protected left-turn movements. Intersections with high through and left-turn volumes may be appropriate sites for continuous flow intersections. There should be a low U-turn demand because U-turns are restricted with this design. Right-of-way adjacent to the intersection is needed for the left-turn ramps. Left-turning vehicles make more stops than at conventional intersections, and may experience a higher delay. The largest benefit from this design is the through traffic.

Advantages

- ✓ Left turns removed from main intersection.
- ✓ More green time for through movements.
- ✓ No conflicts during pedestrian crossing.
- ✓ Smaller footprint than interchange alternative.
- ✓ Air quality.

Disadvantages

- ✓ More stops and delay for left turn movements.
- ✓ Two-stage pedestrian crossing.
- ✓ Layout may not be immediately apparent especially for visually impaired pedestrians.
- ✓ Right-of-way needed may be large.

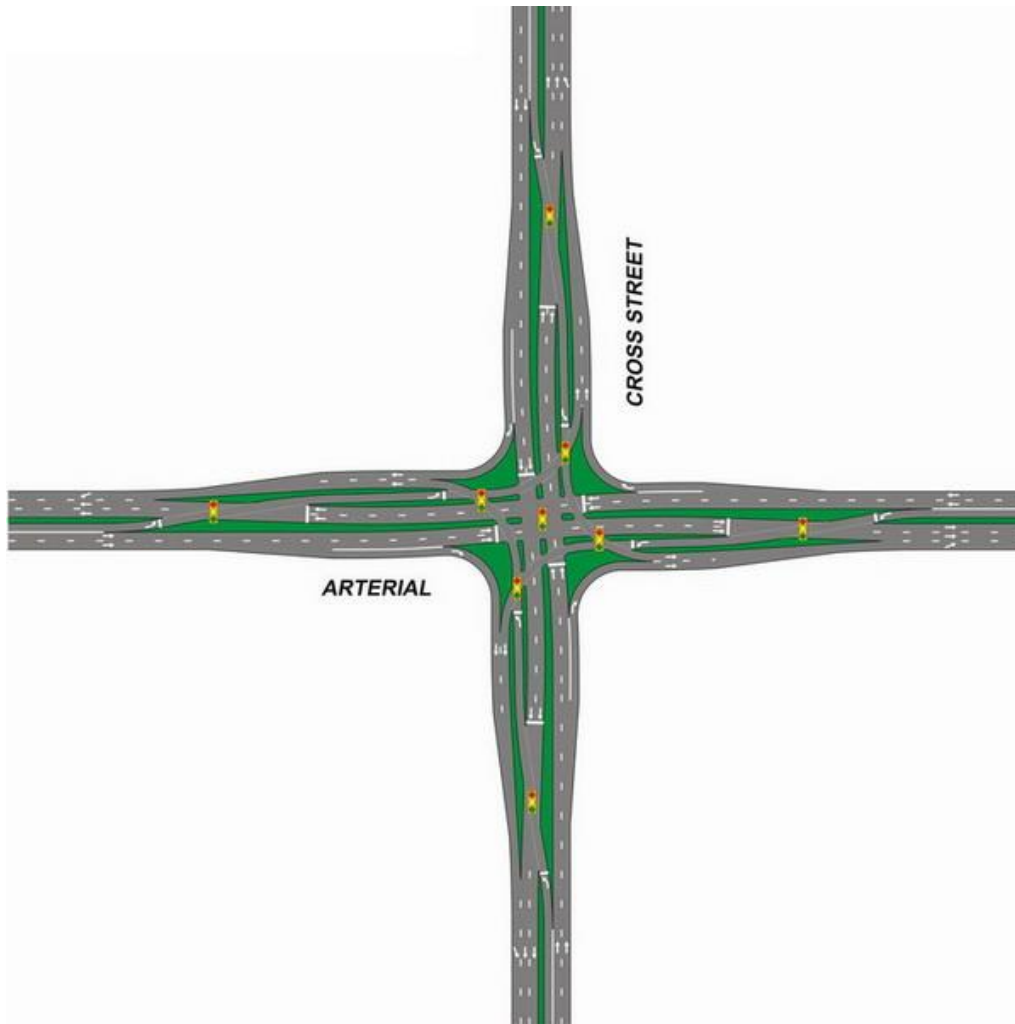


Figure 13: A Continuous Flow Intersection

- ✓ Larger footprint than conventional intersection.
- ✓ Access management.
- ✓ Construction cost.
- ✓ Public information campaign may be needed.

As a case study, the redesign of the Redwood Road/6200 South intersection in Taylorsville, Utah completed in 2010, was found to save 3.5 minutes of travel time per vehicle and 800,000 U.S. gallons of fuel per year, and has 60% fewer crashes in adjacent intersections. There were also considerable delay reductions in nearby intersections and interchanges.

3.12 Paired Intersections

The Paired Intersection concept alternates prohibited left turn movements from the arterial then the cross street at consecutive intersections along an arterial corridor. Circulation to provide adequate turning movement connection to the cross-streets requires a system of two-way "backage" roads parallel to the arterial. This type of intersection is illustrated in [Figure 14: Paired Intersections](#).



Figure 15: Paired Intersections

The guiding principles of the paired intersection concept are the separation of left turns and the emphasis of through-vehicle movements. Highway agencies have been prohibiting left turns from or onto arterials for years (particularly in downtown areas), relying on a good parallel street system or frontage roadways to provide circulation. The paired intersection concept allows this to be done in areas without a pre-existing system of parallel streets or frontage roads.

There is no known intentional application of the Paired Intersection in the US today. Many states have corridors with turning movement prohibitions at some intersections and some corridors are attempting to piecemeal the concept over time (US 70 in Raleigh, NC).

Advantages

- ✓ Reduced delay for arterial through traffic and some left turn lanes.
- ✓ Signal progression for through traffic.
- ✓ Fewer and separated conflict points.

Disadvantages

- ✓ Driver and pedestrian confusion.
- ✓ Increased travel time and distance cross-street and left turning traffic
- ✓ Additional construction, right-of-way, and maintenance on parallel and connecting routes.

Information in this section was obtained from the Maryland SHA and the University of Maryland (2007).

3.13 Split Intersections/ One-Way Pairs

A split intersection, shown in [Figure 16 – Split Pair Intersection](#) requires that the major road approaches to an intersection be converted into two one-way streets. Essentially, the split intersection becomes an at-grade diamond configuration. Rather than one intersection that would operate as a four-phase signal (assuming protected left-turn phasing), two intersections are created that can operate as three-phase signals. The split intersection can be a potential “stage” to constructing a diamond (or other) interchange. The split intersection facilitates smoother traffic flows with less delay and also may improve safety by reducing the number of intersection conflict points.

A split intersection may be considered where significant delays or a high number of left-turn collisions occur.

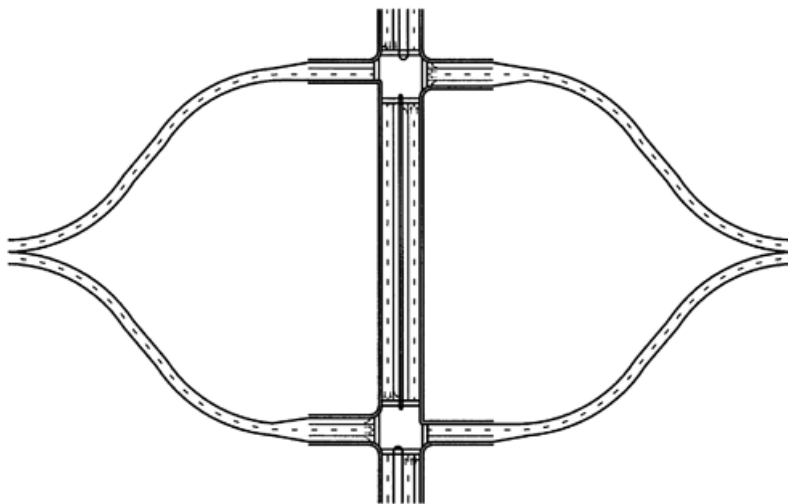


Figure 16 – Split Pair Intersection

Advantages

- ✓ Reduced left-turn collisions.
- ✓ More green time for through movements.
- ✓ Shorter pedestrian crossing distance.
- ✓ Preliminary stage to grade separation.

Disadvantages

- ✓ Wrong way movements.
- ✓ May not be perceived as being pedestrian friendly.
- ✓ High initial construction costs.
- ✓ Right-of-way requirements.

Information in this section was taken from Signalized Intersections: Informational Guide (FHWA, 2004).

3.14 Jug-Handle

A jug-handle is defined as an at-grade ramp provided at or between intersections to permit the motorists to make indirect left turns and/or U-turns. Jug-handles can be used to minimize left turn conflicts at intersections. Many States that have implemented jug-handles to a lesser degree, and these include Connecticut, Delaware, Oregon, and Pennsylvania.

Jug-handles are one-way roadways in two quadrants of the intersection that allow for removal of left-turning traffic from the through stream without providing left-turn lanes. All turns—right, left, and U-turns—are made from the right side of the roadway. Drivers wishing to turn left exit the major roadway at a ramp on the right, and turn left onto the minor road at a terminus separated from the main intersection. Less right-of-way is needed along the roadway because left-turn lanes are unnecessary. However, more right-of-way is needed at the intersection to accommodate the jug-handles.

Figure 17: A Near-Side Jug-Handle intersection illustrates a jug-handle intersection with the ramps located in advance of the intersection. If left-turn movements onto the cross street are problematic, a loop ramp may be constructed beyond the intersection to allow these vehicles to make a right turn onto the cross street, as shown in **Figure 18: A Far-Side Jug-Handle Intersection**.

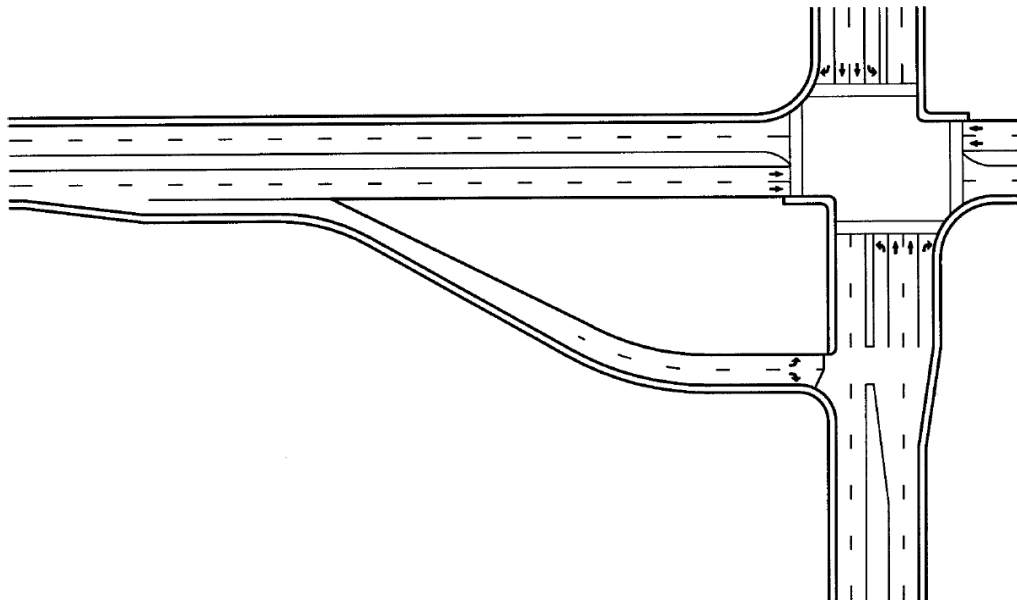


Figure 17: A Near-Side Jug-Handle intersection

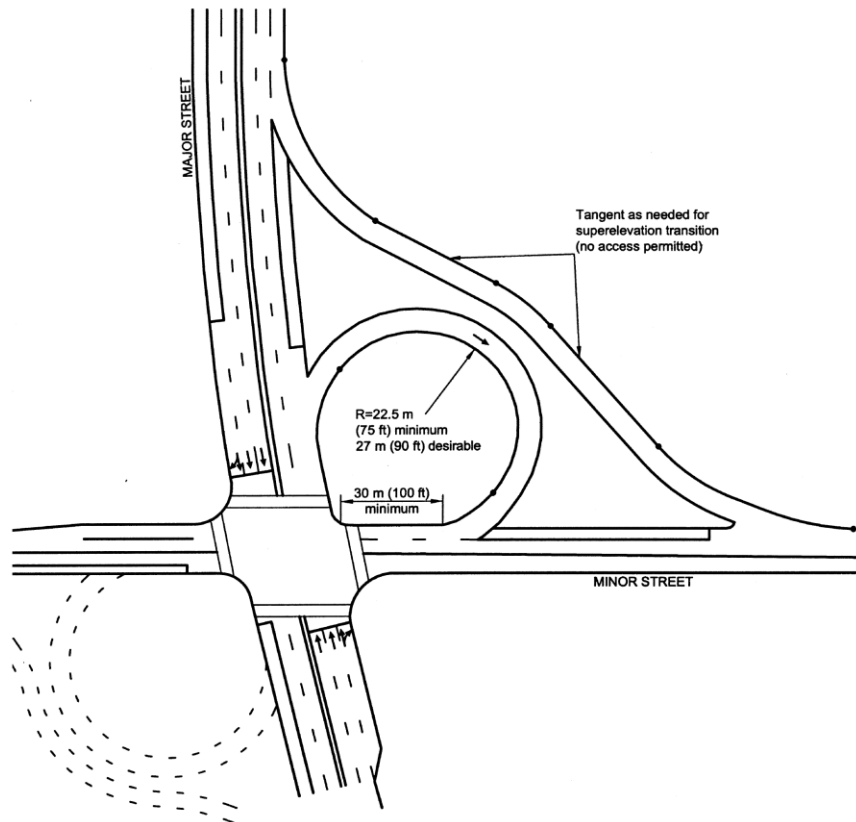


Figure 18: A Far-Side Jug-Handle Intersection

Advantages

- ✓ Potential reduction in left-turn collisions
- ✓ Potential reduction in overall travel time and stops.
- ✓ Pedestrian crossing distance may be less due to lack of left-turn lanes on the major street
- ✓ Pedestrian delay may be reduced due to potentially shorter cycle lengths.

Disadvantages

- ✓ Longer travel time and more stops for left-turning vehicles using the jug-handle.
- ✓ Increased exposure for pedestrians crossing the ramp terminal.
- ✓ Ramp diverges may create higher speed conflicts between bicyclists and motor vehicles.
- ✓ Transit stops may need to be relocated outside the influence area of the intersection.
- ✓ Additional right-of-way may be required.
- ✓ Education may be needed unless good visual/signing cues are provided.

Information in this section was taken from *Signalized Intersections: Informational Guide* (FHWA, 2004).

3.15 Quadrant Intersection

A quadrant roadway intersection includes an extra roadway between two legs of the intersection and is illustrated in *Figure 19: Quadrant Intersection*. Drivers who wish to turn left from either the major or minor road will travel further to do so, but all left turns will be removed from the main intersection. This design creates two additional intersections, which operate as three-phase signals, but the signal at the main intersection can operate as a two-phase signal. The signals at the quadrant ramps should be located a sufficient distance upstream of the main intersection to eliminate the potential for queue spillback.

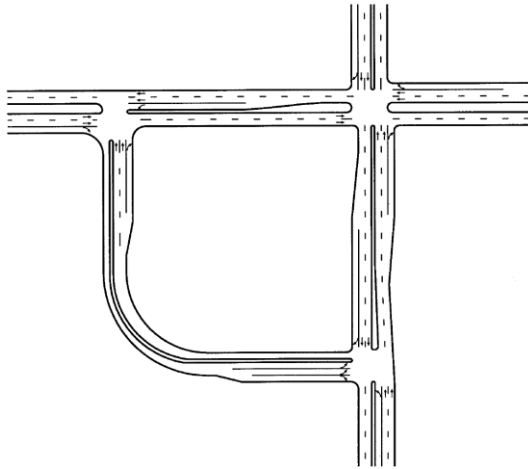


Figure 19: Quadrant Intersection

Intersections of roadways with high through and turn movements may benefit from a quadrant roadway intersection design. If protected left turns at the main intersection are not necessary, more green time can be allocated to the through movements. This application can be useful where right-of-way is limited and there is an existing bypass street on any of the quadrants.

Advantages

- ✓ Potential major decrease in left turn collisions.
- ✓ Potential reduction in delay and queueing.
- ✓ Pedestrian crossing distance at each intersection may decrease.

Disadvantages

- ✓ Potential minor increase in rear-end/intersection-related collisions.
- ✓ Number of intersections to cross increases.
- ✓ If the quadrant roadway does not exist, may be high construction and right-of-way costs.
- ✓ Greater potential for driver confusion.

Information in this section was taken from Signalized Intersections: Informational Guide (FHWA, 2004).

3.16 Grade Separated Interchanges

When traffic volumes become so intense that all at-grade control options will cause excessive vehicular delay, grade separation may be necessary. Additionally, grade separation may be an option in order to solve a safety problem, improve access density, improve connectivity of the minor legs, or provide consistency of traffic control on the mainline. To determine if an interchange will be constructed and what type of interchange to construct, the decision should be based on an adopted corridor study and on good access management practices. Due to the significant funding level needed for interchanges, significant planning should be anticipated and many options/alternatives should be vetted. This should also include analysis of potential at-grade options that could work until funding is available (as an example: constructing an RCI until interchange funding can be identified and programmed).

Table 1 – *Potential Intersection Control by total Daily Entering Volume (ADT)* on Page 7 is included as a guide to assist in determining which intersection options should be evaluated based upon combined average daily traffic (ADT) volumes and when grade separation could be considered as a viable option.

Due to the cost and complexity of grade separation, there are multiple different types of interchange configurations that can be chosen. Though not all configurations need to be explored, several different options should be evaluated. The remainder of Section 3.16 outlines various options to consider. Though not exhaustive, these options should be a good starting point.

3.16.1 Standard/Typical Interchanges

The Minnesota Road Design Manual, Chapter 6, outlines several different common interchange types. It also includes general warrants and project development guidelines that should be considered. In order not to repeat or conflict with the current Road Design Manual, much of the written material and discussion can be found there. (Currently at: <http://dotapp7.dot.state.mn.us/edms/download?docId=1062359>).

Some of the typical configurations shown in Chapter 6 can be seen in *Figure 20: Figure 6-1.03B from the Minnesota Road Design Manual highlighting various interchange configurations.*

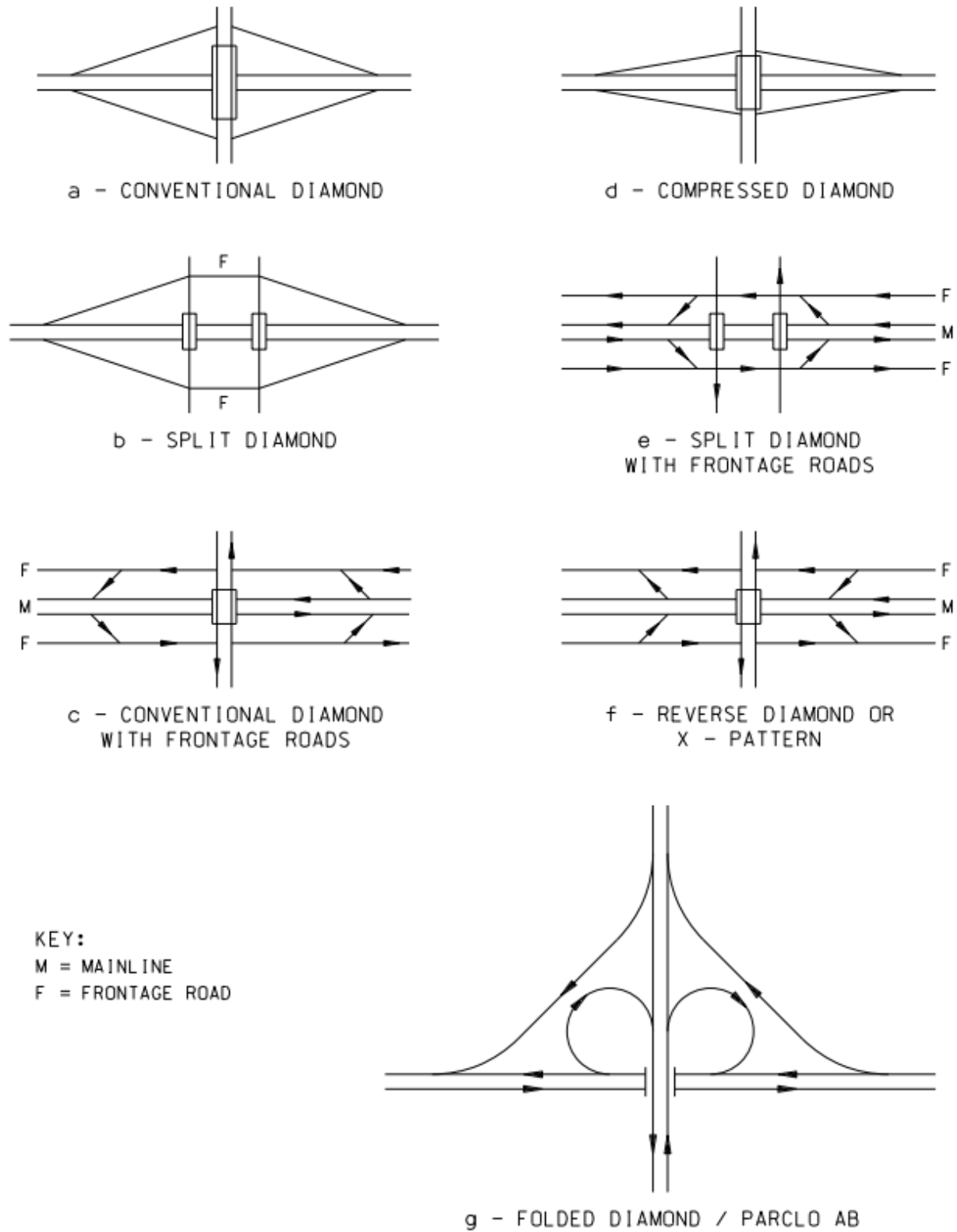


Figure 20: Figure 6-1.03B from the Minnesota Road Design Manual highlighting various interchange configurations

3.16.2 Quadrant Interchange

A quadrant interchange is an interchange that connects to grade separated roadways with only one or two two-way roadways connecting the arterial roadways. The quadrant interchange can be a low-cost and effective design to separate crossing traffic while retaining all movements needed. The most severe crash type, the right angle crash, is effectively eliminated from happening.

This treatment can be used on multilane highways, as seen in [Figure 21: An example of a quadrant interchange](#). This was built near Cannon Falls, MN on USTH 52. The quadrant interchange here connects the major highway (USTH 52) to the minor roadway via two ramps that have two-way traffic on them. All turning movements become right-in right-out on the major highway.

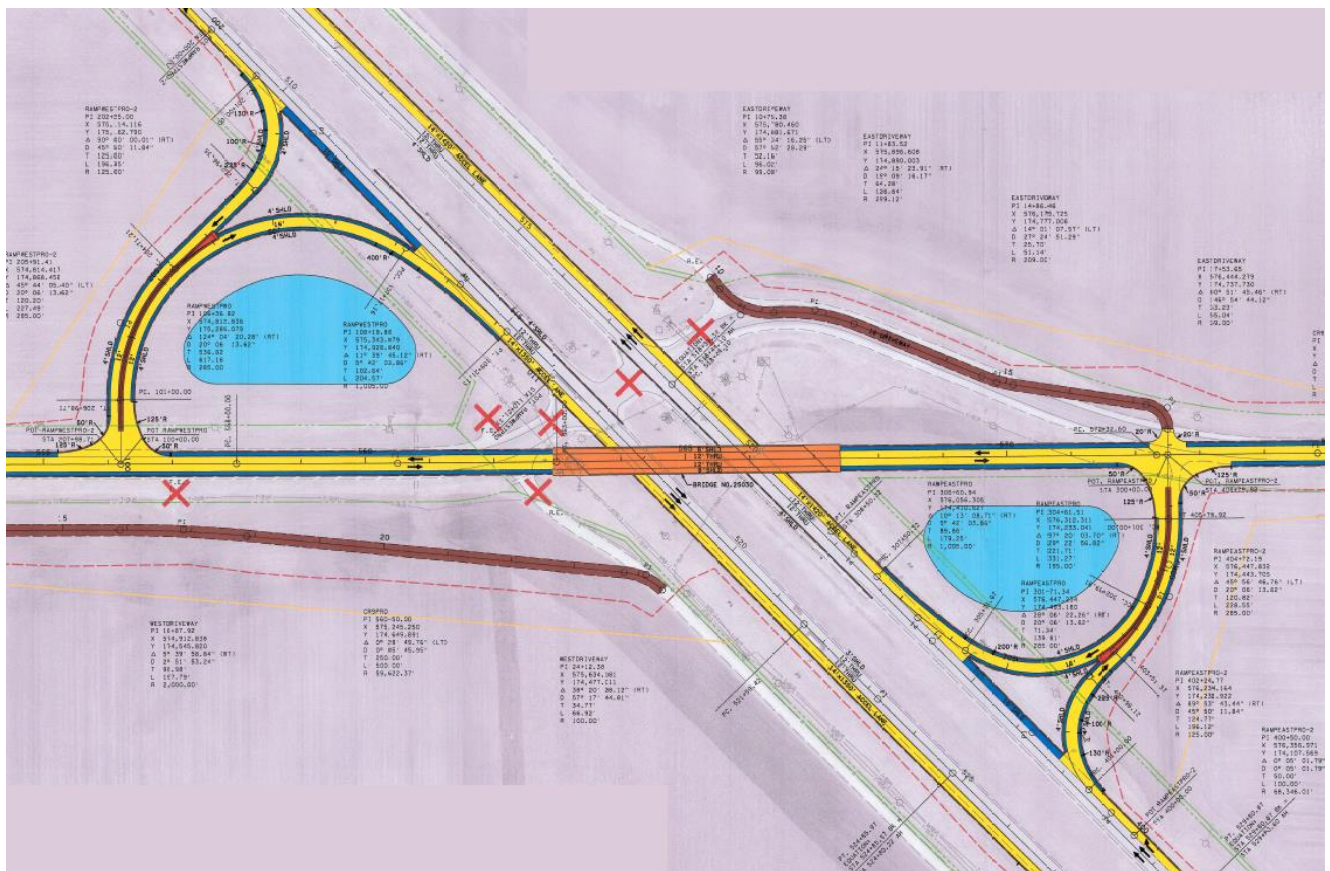


Figure 21: An example of a quadrant interchange. This was built near Cannon Falls, MN on USTH 52.

For connecting two two-lane highways, only a single quadrant can be used, as demonstrated in [Figure 22: A quadrant interchange connecting two-lane two-way highways](#). This is located near Florence, MN.. This alternative could be considered if a grade separation is already completed from another project, or if the separation is occurring for another reason (for an existing rail line).

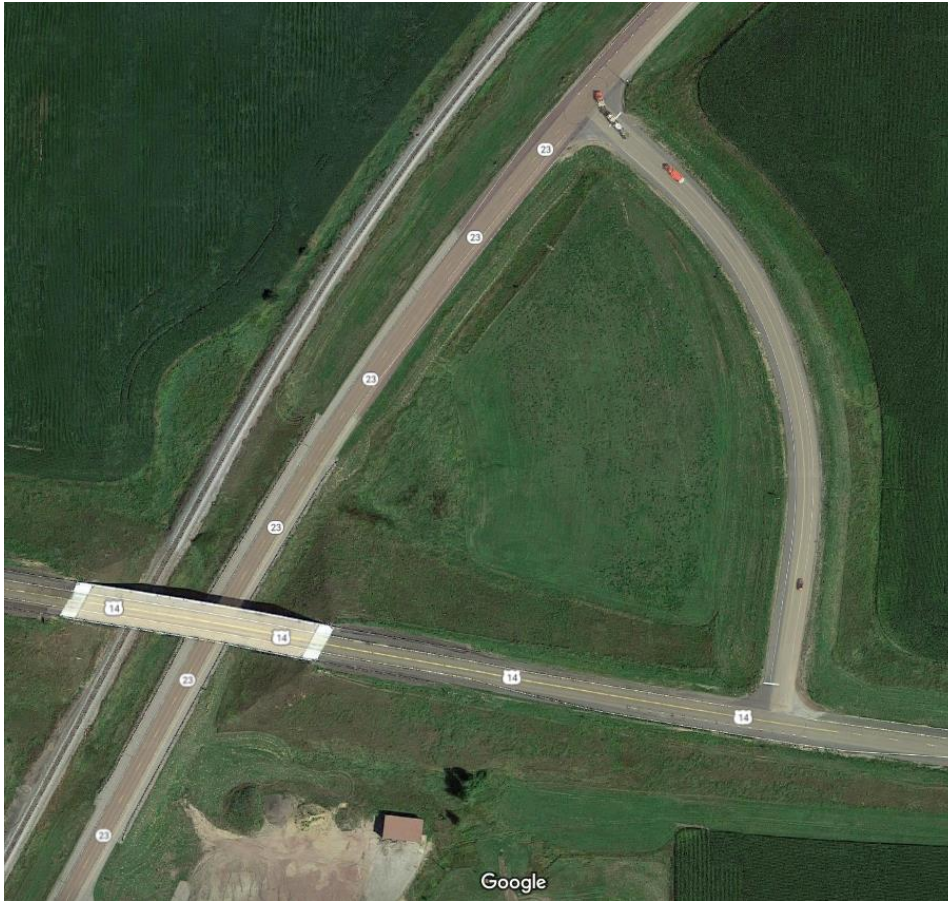


Figure 22: A quadrant interchange connecting two-lane two-way highways. This is located near Florence, MN. (From Google, 2016)

Advantages

- ✓ Elimination/Reduction of Right-Angle Crash potential
- ✓ Lower cost than more traditional interchanges

Disadvantages

- ✓ Higher cost than other at-grade solutions.
- ✓ Cannot handle significant traffic volumes
- ✓ Potential driver confusion.

3.16.3 Grade Separated T-Interchange

A Grade Separated T-Interchange is an option when there is a Tee or Three legged interchange. The concept is similar to the idea of the continuous green t-intersection in that the “top” of the T does not need to stop. The opposing travel direction is then grade separated above (or below) the third leg of the T. This allows all major through movements to continue unimpeded, while only raising/lowering the grade of one direction. See [Figure 23: A Grade-Separated T-Interchange](#). Located near Savage, MN. (From Google, 2016) The minor road intersection under (or over) the grade separation may be signalized or unsignalized depending on the number of vehicles anticipated to turn on and off of the main highway.



Figure 23: A Grade-Separated T-Interchange. Located near Savage, MN. (From Google, 2016)

Advantages

- ✓ Continuous flow of major movements
- ✓ Reduction in conflict points
- ✓ Simplified traffic operations at the crossing intersection
- ✓ Lower cost than more traditional interchanges

Disadvantages

- ✓ Higher cost than other at-grade solutions.
- ✓ Will only work at Tee intersections
- ✓ Difficult for pedestrians or bicyclists to cross

3.16.4 Diverging Diamond Interchange

The Diverging Diamond interchange, also known as the Double Crossover Diamond (DCD) interchange, is a new interchange design that is slowly gaining recognition as a viable interchange form that can improve traffic flow and reduce congestion. Similar to the design of a conventional diamond interchange, the DCD interchange differs in the way that the left and through movements navigate between the ramp terminals. The purpose of this interchange design is to accommodate left-turning movements onto arterials and limited-access highways while eliminating the need for a left-turn bay and signal phase at the signalized ramp terminals. *Figure 24: Illustration of the path maneuvers in a diverging diamond interchange* shows the typical movements that are accommodated in a DCD interchange. The highway is connected to the arterial cross street by two on-ramps and two off-ramps in a manner similar to a conventional diamond interchange. However, on the cross street, the traffic moves to the left side of the roadway between the ramp terminals. This allows the vehicles on the cross street that need to turn left onto the ramps to continue to the on-ramps without conflicting with the opposing through traffic.

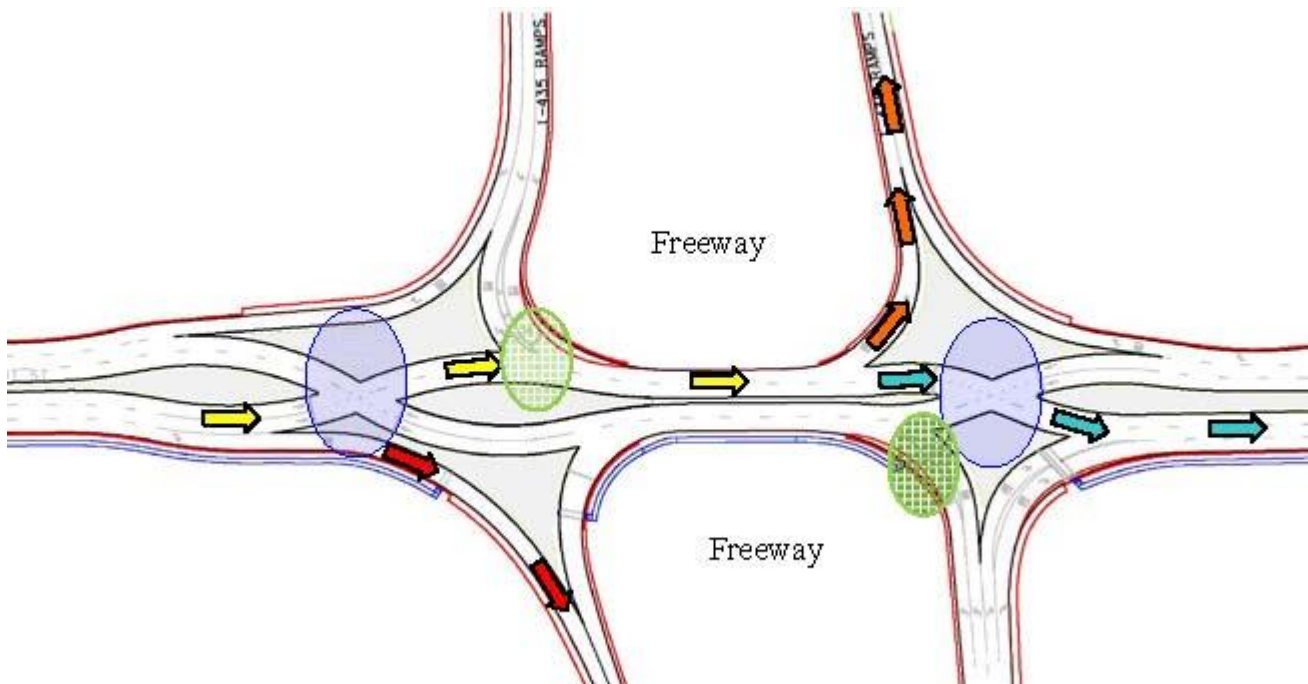


Figure 24: Illustration of the path maneuvers in a diverging diamond interchange

As in a conventional diamond interchange, the right-turn movements from the cross street to the ramps occur at the ramp terminal intersections. Using *Figure 24: Illustration of the path maneuvers in a diverging diamond interchange*, which shows a situation where the freeway mainline passes under the crossroad, the through and left-turn movements (depicted as yellow arrows) are crisscrossed so that the eastbound traffic (moving right) travels on the roadway that is to the left, and the westbound traffic (moving to the left) travels on the roadway to the right in the interchange area. The intersections where

the opposite directions of travel cross are under signal control. Crossing the bridge, vehicles travel on the opposite side of the road than is normal. After crossing the bridge, the left-turn movements proceed to the ramps of the major street without any further signal control (depicted as orange arrows). The opposing right-turn movements merge with the left-turning traffic on the ramp. The through movements on the crossroad cross over to the right side at the second signal intersection and continue in their respective directions (shown as blue arrows). In addition, the red arrows depict side street right-turn movement while the blue circles show the signal-controlled crossovers. Under this configuration, the two crossovers operate under signal control with two phases.

Pedestrians and non-motorized users are typically directed to the center of the bridge to walk between the opposing lanes, which are protected by barriers. Users then cross the traffic lanes, often with the assistance of signalized intersections and countdown timers. See [Figure 25: An information flier explaining the components and how to use a diverging diamond interchange](#). for an informational flier that was used to educate the general public near St. Cloud, MN.

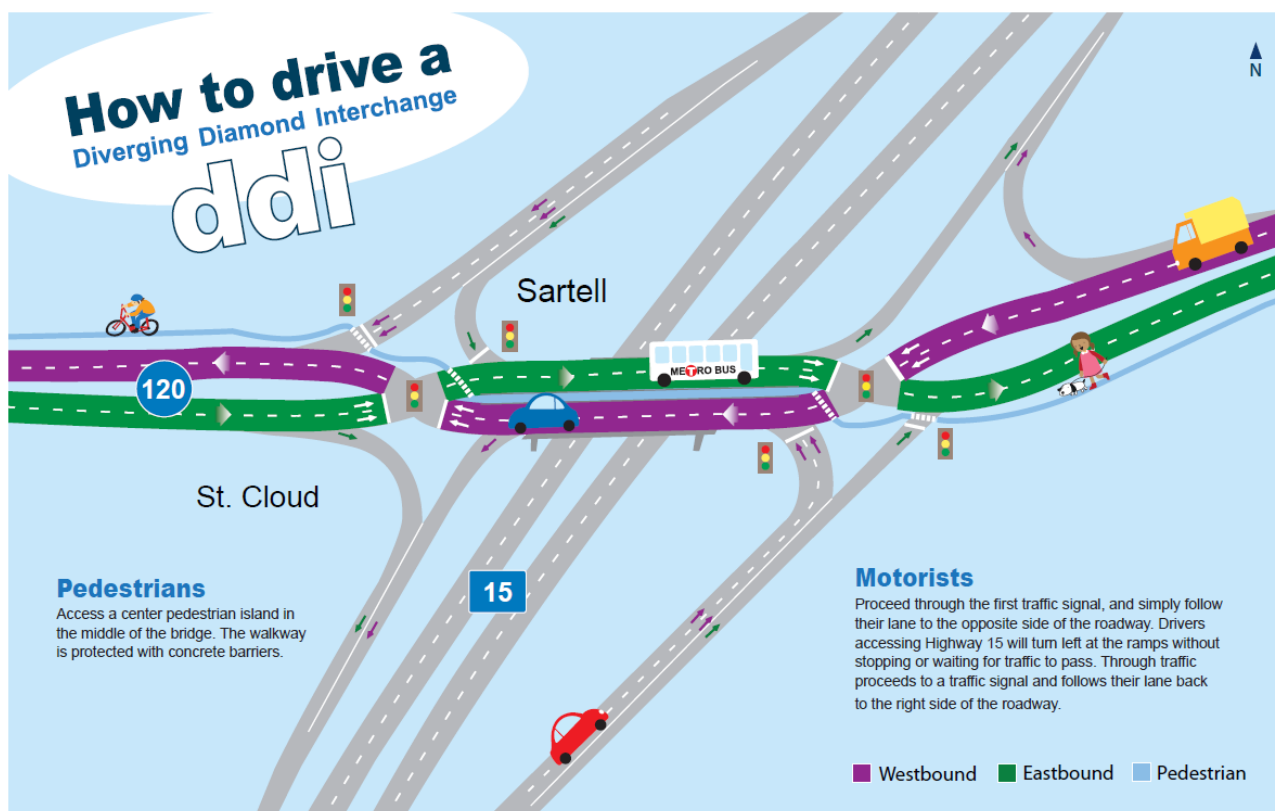


Figure 25: An information flier explaining the components and how to use a diverging diamond interchange.

Advantages

- ✓ Major capacity improvements versus a standard diamond
- ✓ Reduction in conflict points
- ✓ Narrower bridge is needed (lowering costs)
- ✓ Simplified traffic operations at the crossing intersections/ two phase operations
- ✓ Can be retrofitted on existing bridges

Disadvantages

- ✓ Driver confusion from driving on the “wrong” side.
- ✓ Pedestrian use is not straightforward or intuitive for users.
- ✓ Ramps need to be in a diamond format
- ✓ Most effective where there is significant turning maneuvers at the interchange

3.16.5 Single Point Interchange (SPUI)

The Single Point Interchange, also known as a single point urban interchange (SPUI), is an intersection type that controls and combines all turning and through movements into one single intersection, instead of two separate intersections at more traditional interchanges. See [Figure 26: An illustrated Single Point Urban Interchange](#) for an illustration of the layout of a typical SPUI. Several SPUI's have been built in Minnesota and tend to function well for their intended purpose.

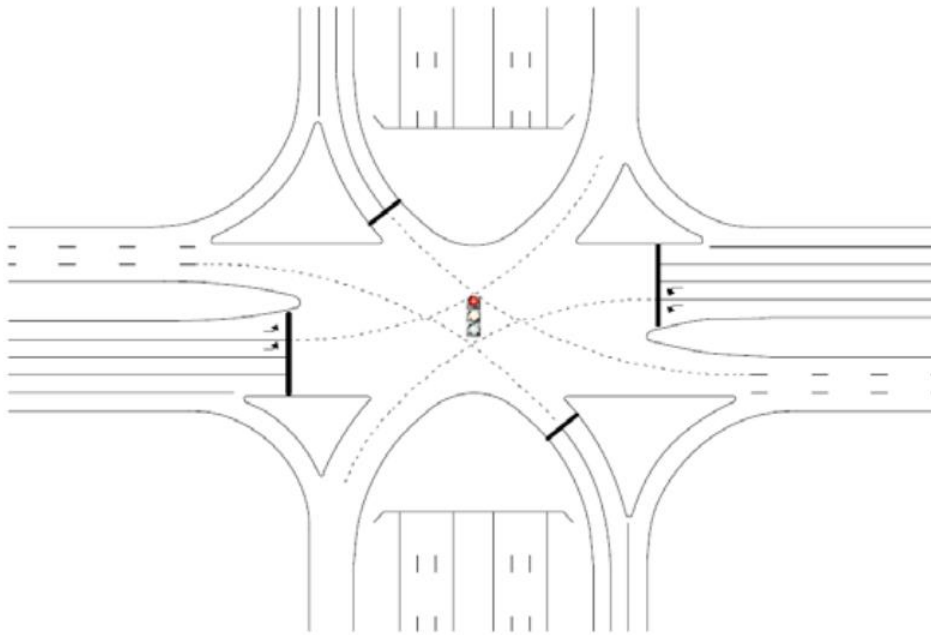


Figure 26: An illustrated Single Point Urban Interchange. (From Transportation Research Board)

Advantages

- ✓ Major capacity improvements versus a standard diamond
- ✓ Delay reduction versus traversing two separate intersections
- ✓ Reduction in total conflict points
- ✓ Simplified traffic operations at the crossing intersections/ three or four phase operations
- ✓ Signal timing can be easier to coordinate with adjacent signalized intersections

Disadvantages

- ✓ Pedestrian and bicyclists have difficulty navigating this
- ✓ Ramps need to be in a diamond format
- ✓ Very large and oddly shaped bridge is needed
- ✓ Typically cannot be retrofitted into standard diamond configurations
- ✓ Can be very costly due to large and peculiar bridge design needs

3.16.6 Roundabout Terminals

This interchange uses roundabouts as the ramp terminals intersection control. See [Figure 27: An interchange that uses roundabouts as the ramp terminals](#). Located on Highway 610 and Zachary Lane. (From Google Maps, 2016). The benefits of this interchange is that it provides many of the benefits that roundabouts also provide.

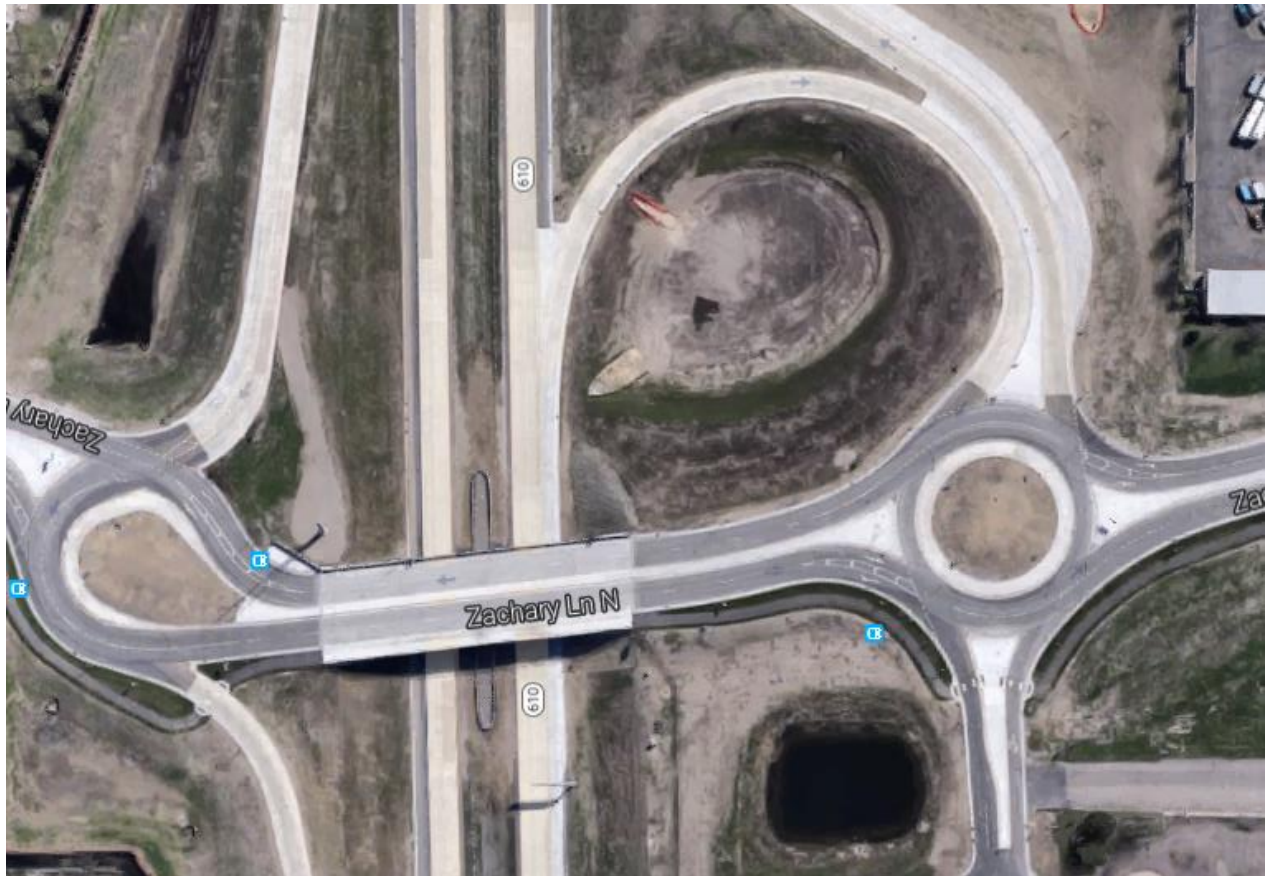


Figure 27: An interchange that uses roundabouts as the ramp terminals. Located on Highway 610 and Zachary Lane. (From Google Maps, 2016)

Advantages

- ✓ Terminals can have capacity improvement over signalized intersections
- ✓ Can greatly reduce the needed bridge width, since items such as turn lanes are not needed.
- ✓ Reduction in total conflict points
- ✓ May be able to tie in local road network more easily

Disadvantages

- ✓ Nearby signalized intersections may cause queueing issues and backups
- ✓ Potentially more right-of-way needs

3.16.7 Echelon Interchange

A potential for at-grade intersections with significant volume is to separate the intersection into two grade-separated intersections that can operate independently from one another. This option has been called the Echelon Interchange. One approach on both the arterial and intersecting cross-street are elevated on structure as they intersect, while the other approach halves intersect at-grade. The result is a symmetrical but offset pair of two-phase intersections separated by grade, both operated by two-phase signals as in the meeting of two one-way streets. This type of interchange is illustrated in [Figure 28: An illustration of the Echelon Interchange](#).

The Echelon design was born of necessity for a single intersection improvement project at US 1 and NE 203rd Street in Aventura, Florida. This design location, opened in June 2000, is currently the only known application in the world. The Echelon Interchange was so named by the late Don Beccasio of the Florida Department of Transportation's Planning Division, who worked on this initial design application. The design's feature of one intersection offset and over another reminded him of the U.S. Navy Flight Demonstration Team's "Echelon" formation, where each plane flies offset and over one another.

The Echelon interchange has specific application to arterial roadways. The Echelon interchange is unique in that there are no free-flow movements. This interchange would not be suitable on a freeway facility. The Echelon interchange is a simple concept that uses retaining wall structures to elevate one-half the roadway on each intersection approach to meet at an elevated intersection, while the other halves intersect at-grade. The result is a symmetrical but offset pair of one-way street meetings separated by grade. The design provides logical movements from each approach and requires little advance signing. Motorists experience the same decision processes as at an intersection of two one-way streets.

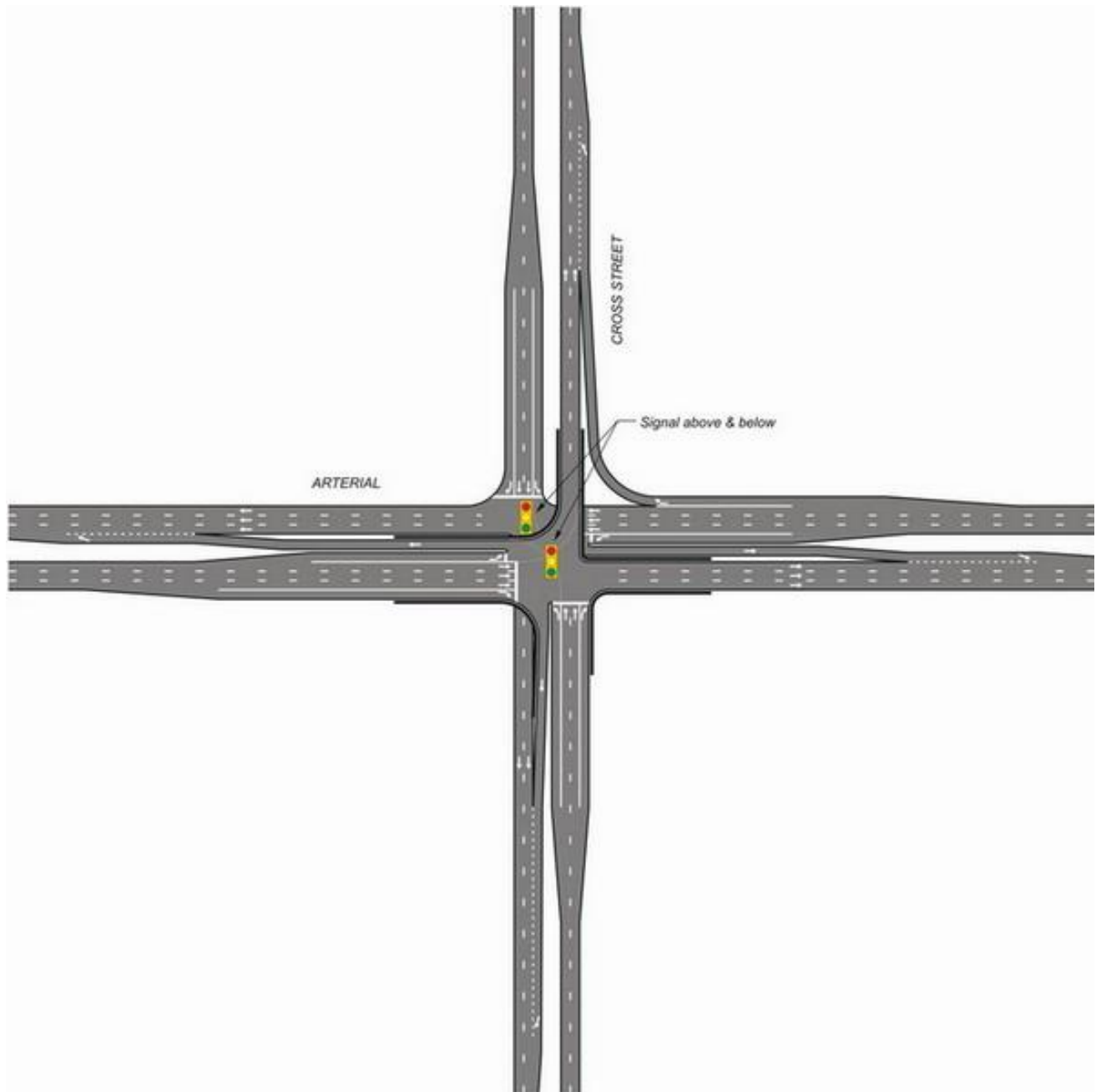


Figure 28: An illustration of the Echelon Interchange.

The Echelon design very is pedestrian friendly, as all pedestrian movements can be made directly on the at-grade part of the intersection, which operates under two-phase signal control. Shorter signal cycles mean shorter crossing wait times and pedestrians cross only one travel direction.

The Echelon design provides great flexibility for engineers and designers, as any one of the four through-movements and connecting ramps can be placed at-grade or elevated, depending on volume

forecasts, right-of-way constraints and/or intersection geometric features (such as a rail crossing or intersection skew).

In a study comparing operations of the Echelon versus the Compressed Diamond and single-point urban interchange (SPUI) designs , the Echelon was able to process the most vehicles and had no failing LOS, while the Compressed Diamond had two failing LOS approaches under the same volume conditions, and the SPUI had

Advantages

- ✓ Signals can operate with only two-phases
- ✓ Significant delay reduction for all movements
- ✓ Can be designed to handle pedestrians safely
- ✓ Can be intuitive to drivers

Disadvantages

- ✓ Significant construction costs, especially retaining wall needs
- ✓ Potentially more right-of-way needs
- ✓ All movements will still have the potential to stop
- ✓ Cannot be used on freeways
- ✓ Difficult concept for public to understand and accept

Information in this section was obtained from the Maryland SHA and the University of Maryland (2007).

3.16.8 Center Turn Overpass Interchange

A similar concept to the Echelon Interchange is the Center Turn Overpass Interchange. The concept is to have the left turn traffic separated from arterial and cross-street thru and right-turn movements by elevating all left turns to a separate, elevated intersection using narrow ramps within the median. Unlike freeway-style flyover designs, the CTO ramps fit vertically within a wide center median, replacing dual left-turn bay slots with two-lane roadways on structure. Both the elevated and at-grade intersections are controlled by a simple two-phase signal. As left-turning traffic is grade-separated from through-traffic, heavy turn volumes are less likely to choke the intersection compared to a conventional at-grade intersection.

Left turn traffic descends from the elevated intersection and merges into thru traffic lanes. *Figure 29: The Center Turn Overpass Interchange* illustrates this interchange.

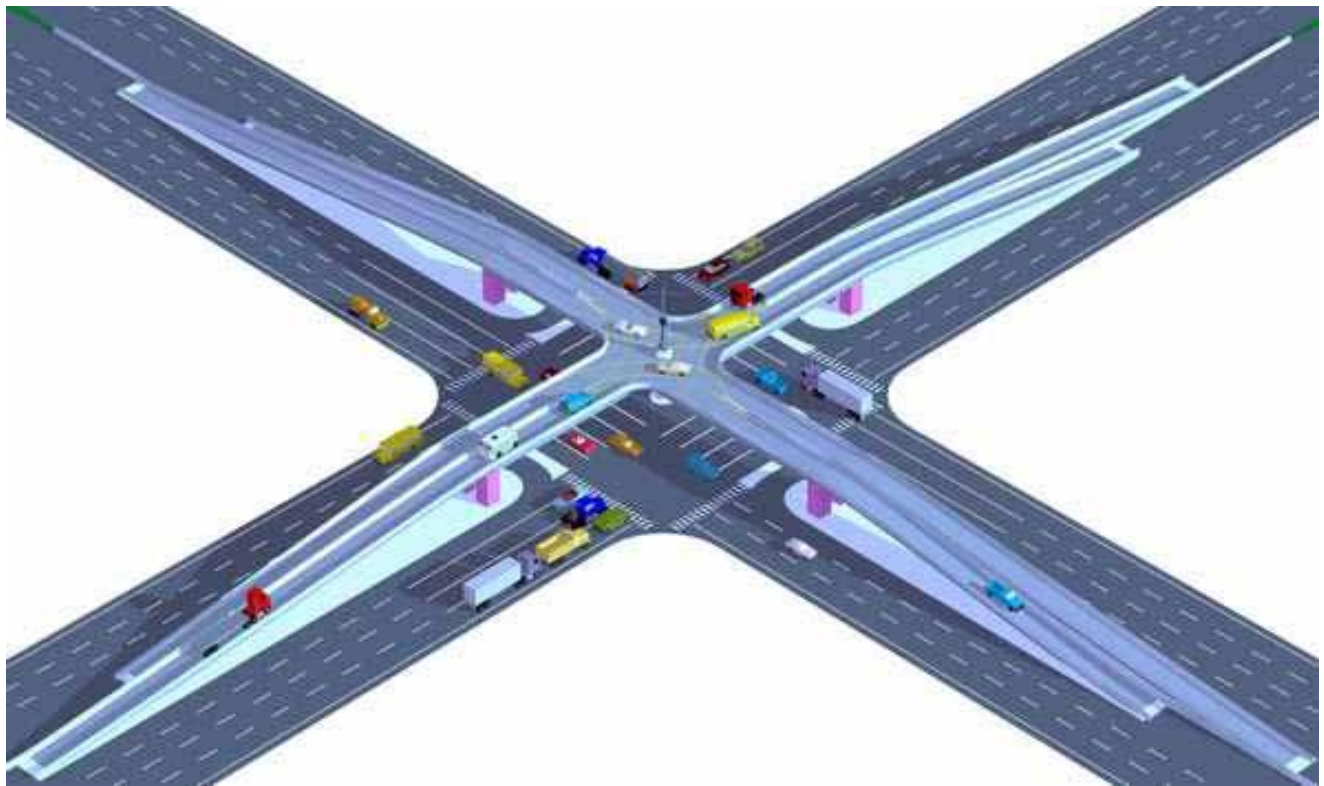


Figure 29: The Center Turn Overpass Interchange

The CTO design concept is relatively new and is continuing to be refined, and there is currently no design application of its kind in the U.S. Several highway agencies have considered the CTO design (Maryland, Nevada, North Carolina) because of its ability to handle large turning-traffic volumes and minimize impacts to adjacent properties and right-of-way, but so far all have selected to implement a more conventional design or no immediate improvement at all. There has not been a full CTO Intersection design implemented to date in the U.S. by which to draw any specific lessons learned.

The CTO can be simpler to construct than a traditional fly-over overpass. Column and retaining wall supports are confined to the center median, minimizing their impact on the outside right-of-way and adjacent properties. In locations with greater concerns about property access, the CTO design could be modified to permit ground-level left turns for direct access to corner parcels. These modifications would also support access by emergency and over-sized vehicles. The U-turns would not have protected signal phases, thus negating some of the benefits of the two-phase intersections. In a study comparing operations of the CTO to several other arterial interchange designs, the CTO design was found to have considerably greater capacity compared to the traditional Diamond interchange, and had the greatest operational benefits on a six-lane or wider arterial with moderate-to high left-turn volumes. Capacity studies have shown that the CTO can have up to 75 percent more green time allotted for left turns compared to dual left-turn lanes at a conventional intersection, and ground level through-volumes can receive up to 40 percent more green time.

Pedestrians are accommodated on the ground level and can make one or two-stage crossings. Pedestrian phases are at greater frequency due to shorter cycle lengths, and pedestrian crossing with left-turning vehicles are eliminated by grade.

Snow and ice removal may be problematic, as the slender ramp approaches leave little room for snow on the shoulders, and ice may be a concern on shorter, steeper grades. Crash response and clearance could also be an issue on minimal width ramp approaches. Sight distance issues for both the elevated and at-grade roadways can be overcome with a wider, more open structure design made possible using steel construction.

Advantages

- ✓ Signals can operate with only two-phases
- ✓ Significant reduction for all movements
- ✓ Can be designed to handle pedestrians safely
- ✓ Can be intuitive to drivers

Disadvantages

- ✓ Significant construction costs, especially retaining wall needs
- ✓ All movements will still have the potential to stop
- ✓ Cannot be used on freeways

Information in this section was obtained from the Maryland SHA and the University of Maryland (2007).

3.16.9 Fully Directional / System Interchange

The fully directional system interchange is the ultimate buildout of an intersection. These interchanges are designed to handle extremely large numbers of vehicle on all of the approaches. The overall need of this interchange is to allow two high-volume highways to cross without any need for any maneuver (right, thru, or left) to be stopped by an at grade intersection or traffic signal (ramp meters may still stop traffic). Due to issues with potential weaving, several different variations exist to reduce this potential and ensure all movements move through the interchange unimpeded. The Minnesota Road Design Manual illustrates several basic fully and semi-fully directional interchanges. *Figure 30: Semi-Directional Interchanges* and *Figure 31: Directional and Fully-Directional Interchanges* are from Chapter 6 of the Minnesota Road Design Manual.

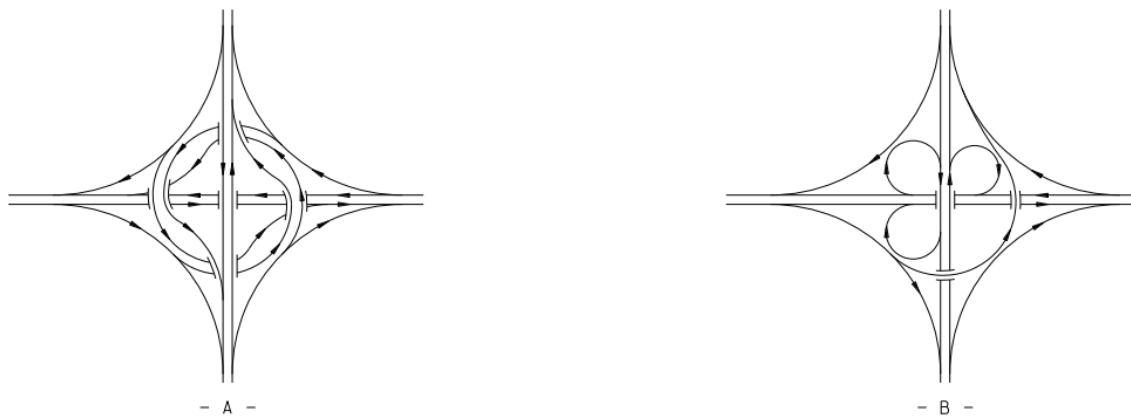


Figure 30: Semi-Directional Interchanges

Due to the high cost of construction and long term maintenance needs (ramps, bridges, pavement, etc), the system interchange should be reserved for all but the highest volume interchanges and Interstate to Interstate connections.

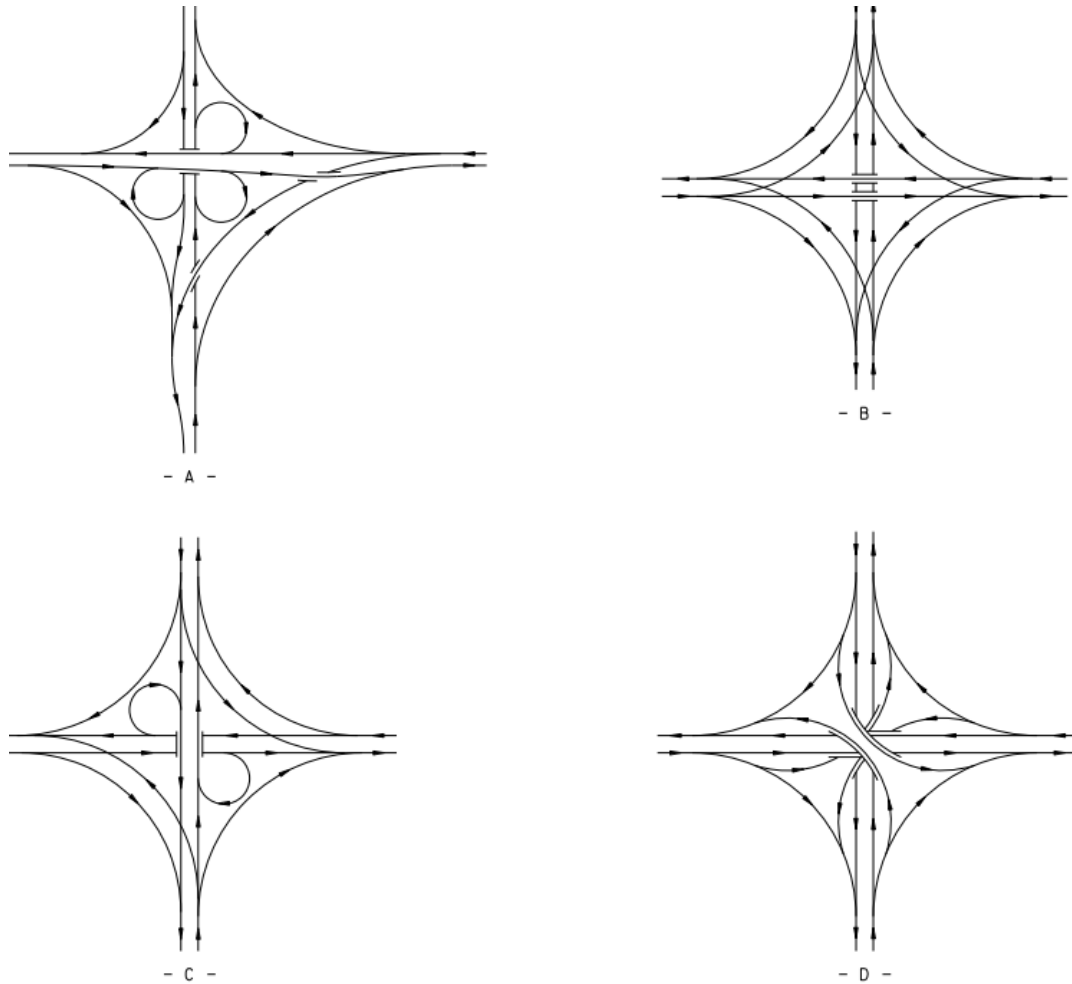


Figure 31: Directional and Fully-Directional Interchanges

Advantages

- ✓ All movements can progress through without stopping
- ✓ Significant Capacity with little delay
- ✓ Complete elimination of all crossing conflicts. Only merging and diverging conflicts remain.

Disadvantages

- ✓ High cost due to bridges, pavements, and long term maintenance needs
- ✓ Significant Right-of-Way needs to accommodate all movements at high speeds
- ✓ Weaving can cause interchange breakdown
- ✓ Significant signing is needed to clearly delineate movements

4.0 Intersection Enhancements

Once the type of intersection or interchange has been selected, the main purpose of this guide has been achieved. The intersection control selected will be the most important factor for how the intersection will perform in operations, safety, and the quality of service for all the users. However, certain enhancements can be added to intersections that can improve how the intersection operates, or performs in regards to safety. Intersections are one of the most complex and at-risk components of the transportation network. Nearly 40% of all crashes occur in or near an intersection as the result of vehicles using or approaching an intersection.

Enhancements should be selected with regards to the benefits they provide versus the cost of adding such enhancements, especially if reconstruction will be needed (when the cost can be substantially higher). The enhancements listed here are not an exhaustive list, nor will provide clear guidance on when to use such enhancements. This section is meant to educate engineers and transportation officials on potential choices that are available to help improve intersections.

4.1 Enhanced Striping and Signing

One of the most important reasons for signing and striping can be to make drivers aware of an approaching intersection, and the traffic control that governs that intersection. Signing can be used to let drivers know about an approaching stop sign, signalized intersection, or a roundabout. Signing and striping can also be used to give information to lessen confusion once the driver is at the intersection, such as available maneuvers (right only) or direction to certain locations.

Due to the low cost of signing and striping, this is often the first and only enhancements that are given to an intersection to improve safety and operations. Caution must also be exercised to not “clutter” an intersection and provide so much information as to overwhelm drivers.

For rural thru-stop intersections, a simple signing package has been recommended to help improve safety and reduce driver confusion. This can consist of an oversized stop sign, painted stop bars, junction signing, “Stop Ahead” signing and/or markings. See [*Figure 32: An example of enhanced signing and striping at a rural thru-stop intersection*](#) (Minnesota Traffic Safety Fundamentals Handbook, 2015).

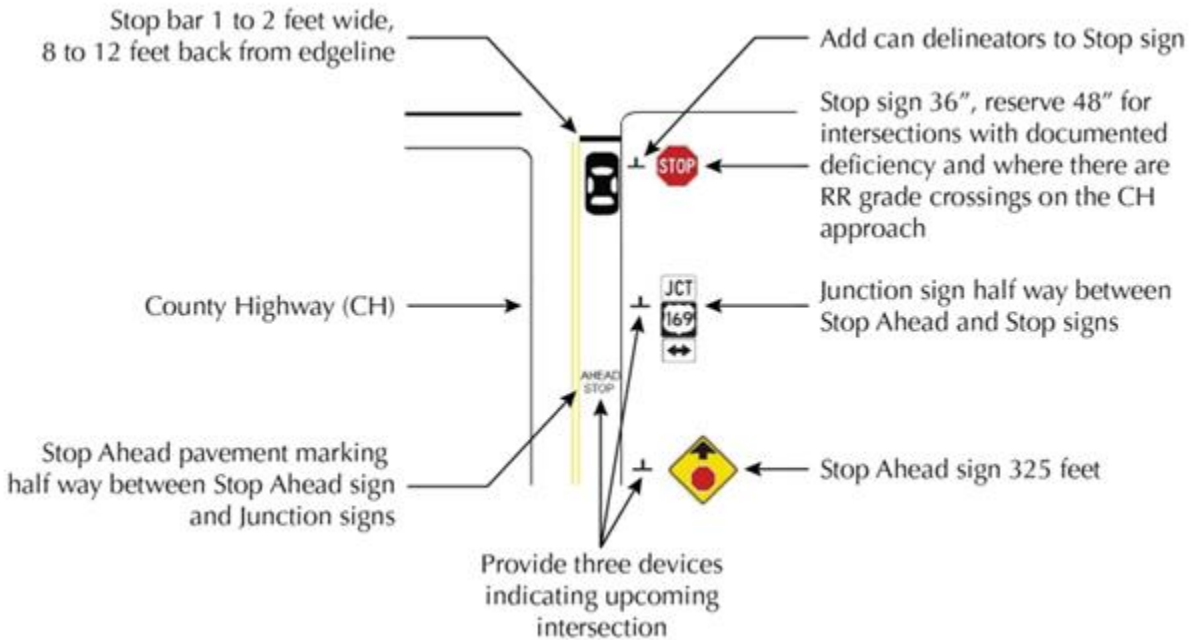


Figure 32: An example of enhanced signing and striping at a rural thru-stop intersection (Minnesota Traffic Safety Fundamentals Handbook, 2015)

Chicanes can also be a tool in more urban areas to get drivers to slow down and become aware of an approaching intersection. Chicanes are either painted or curbed edges that have drivers adjust their path as they approach the intersection. See **Figure 33: An illustration of a chicane (FHWA Safety Webpage)**.

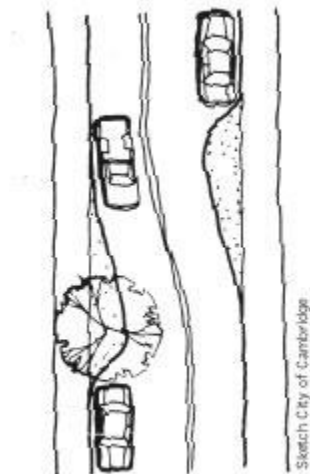


Figure 33: An illustration of a chicane (FHWA Safety Webpage)

4.2 Illumination/Lighting

The purpose of roadway lighting is to attain a level of visibility which enables the motorist and pedestrian to see quickly, distinctly, and with certainty all significant detail, notably the alignment of the road (its direction and its surroundings) and any obstacles on or about to enter the roadway. Intersection illumination can be done to fully illuminate the intersection and approaches, or simply as to help drivers delineate a destination or roadway with a landmark location. Intersection lighting is considered a low-cost and effective device for creating a safer intersection, especially in rural settings. Most of the more increased intersection control types typically have their own standards and procedures for illumination that should be followed during the project development.

For more information on intersection lighting, refer to the MnDOT Roadway Lighting Design Manual.

4.3 Turn Lanes

Turn lanes at intersections provide drivers with a location to both slow down and wait for the selected gap to complete the turning maneuver. Turn lanes can improve both operations of an intersection and the safety of motorists as well. Due to the increased cost in construction and maintenance, turn lanes should be evaluated to ensure that traffic volumes warrant the need.

For signalized intersections and operational considerations, an analysis should be part of the ICE process, and turn lanes (and the number of them) should be detailed weighing the various factors of intersection delay, right-of-way needs, safety impacts, and the anticipated costs. With additional turn lanes, come additional risks for pedestrians and non-motorized users, with each lane adding additional width and exposure that needs to be crossed. With the added width, additional time may be needed for the non-motorized users to safely cross the intersection, and may also impact signal timing operations as well.

When turn lanes are being considered for safety benefits, an analysis with the Highway Safety Manual may be beneficial to show the potential crash reduction and to quantify the benefits. A crash analysis for intersections with crash issues may help to quantify the benefits as well.

4.4 Intersection Conflict Warning Systems

Intersection Conflict Warning Systems, or Rural Intersection Conflict Warning Systems (RICWS), provides supplemental warning to drivers of other vehicles approaching the intersection. RICWS consists of a combination of a minor road warning and major road warning, or major road warning only. The minor road warning will warn drivers that there are major road vehicles approaching the intersection. The major road warning will warn drivers that there are vehicles on the minor road that are entering the intersection.

The systems are composed of signing, vehicle detection, and dynamic warning beacons. Drivers on the major road will see a static “Entering Traffic” with a “When Flashing” plaque. Drivers on the minor road will see a constantly illuminated blank-out sign message “Traffic Approaching” with a “When Flashing” plaque. In the case of a malfunction or power outage, drivers on the minor road will not be given a message as the blank-out sign will be black/off. Though this is the current configuration used in Minnesota, this is not the only option, nor has it been standardized yet.

The benefits of these systems are that they provide real-time information and warning to drivers about current traffic conditions. Current studies have shown crash reductions ranging from 25-30%. See [Figure 34: An example of the Intersection Conflict Warning System](#). The left image is what a minor road driver would see. The right image is what a major road driver would see.



Figure 34: An example of the Intersection Conflict Warning System. The left image is what a minor road driver would see. The right image is what a major road driver would see.

4.5 Traffic Signal Coordination Concepts

As a corridor becomes more signalized and has additional traffic and congestion, coordination to increase throughput and reduce delay may be worth exploring and implementing. Coordination can be an effective tool that keeps traffic moving in an orderly fashion by reducing the amount of stopping and starting time within a platoon of vehicles. Coordination can be achieved in multiple ways, and controlled from a central controller system (see below). Coordination can be achieved in such ways as non-interconnect/Time Based Coordination (NIC/TBC), Interconnected timed system, interconnect traffic responsive system, interconnected actuated systems, adaptive traffic systems, Advanced Traffic Management Systems (ATMS). Time-Space diagrams within software models are used by traffic professionals to assist in implementing cycles, offsets and splits used for signal coordination.

More information can be found in MnDOT Traffic Signal Timing and Coordination Manual.

4.6 Central Controller Systems

Traffic-signal central control systems coordinate individual traffic signals to achieve network-wide traffic operations objectives. These systems consist of intersection traffic signals, a communications network to tie them together, and a central computer or network of computers to manage the system. Coordination can be implemented through a number of techniques including time-base and hardwired interconnection methods. Coordination of traffic signals across agencies requires the development of data sharing and traffic signal control agreements. Therefore, a critical institutional component of Traffic Signal Central Control is the establishment of formal or informal arrangements and agreements to share traffic control information as well as actual control of traffic signal operation across jurisdictions. A traffic-signal systems purpose is to assign-right-of way in the most efficient way, given the variable traffic demands throughout the day. Signal Coordination provides arterial efficiencies that go beyond a stand-alone signal. The central control system provides features that improve the traffic engineer's ability to achieve area-wide and cross agency efficiencies. These are primarily access control features. They provide access to the intersection signal controller for maintenance and operations. The more complete and convenient the access, the more efficient the operator will be and the more effective the corridor and system. In addition to control of traffic signals, modern systems also provide wide-ranging surveillance capabilities, including various kinds of traffic detection and video surveillance. They also provide more powerful traffic-control algorithms, including the potential for adaptive control and predictive surveillance.

From the "Advanced Transportation Management Technologies", Chapter 3. 1997.

4.7 Flashing Yellow Arrow

The flashing yellow arrow is a newer concept that changes the “green ball”/permissive left turn phase at signalized intersections to a yellow arrow that flashes. Studies have shown that this flashing yellow arrow (FYA), is more intuitive to drivers to help them yield the right-of-way to oncoming motorists. MnDOT now requires the use of FYA for new traffic signal designs with a dedicated left turn lane unless the left turner has limited sight distance. Not only does it fit the requirements of the MN MUTCD for lefts with an exclusive lane, but it also provides flexibility in operation. For example, the FYA can be changed from a permitted only, to protected-only, or protected-permissive on a time of day basis. Therefore, an indication could run protected during times when required and permitted when not. This time-of-day operation is determined by a number of factors. Primary factors that play into the decision are the number of left turn vehicles versus thru vehicles, opposing left turn lane offsets and approach speeds.

The use of a FYA is required whenever permissive left turn operations are allowed and a dedicated left turn lane exists. However, the FYA indication should not be used and a protected only indication should be used when the following conditions exist; intersection geometrics creates a conflicting left turn path or the mainline left turner has limited sight distance as defined in the current AASHTO “A Policy on Geometric Design of Highways in Streets.”

4.8 Confirmation Lights

Right angle crashes are the most common type of severe crash at signalized intersections, and research has found that the primary contributing factor to right angle crashes is likely intentional red-light running. Commonly, law enforcement has difficulty providing sufficient enforcement, and drivers have no fear of red-light running consequences associated with enforcement. Local law enforcement officers typically indicate that they lack the staffing needed to safely monitor red-light running since one officer is needed to observe the infraction, and one would be needed to issue the citation downstream of the incident. Due to this need, many local law enforcement agencies lack the staff or budget to properly enforce red-light running

However, new technology has been developed that allows one officer to monitor intersections from the downstream side; these “confirmation/enforcement lights” consist of a small blue light typically mounted to the back side of the traffic signal mast arm or indication. See [*Figure 35: A confirmation light mounted to the back on an existing signal mast arm.*](#) The lights are wired into the red light circuitry so that the blue light comes on at the same time as the red light for approaching traffic. This strategy is being used increasingly in states that do not allow the use of cameras for enforcement (such as Minnesota). Law enforcement officials acknowledge that red-light running is a concern, and they support using the new strategy.

Usage of these lights typically requires that local law enforcement provide added levels of enforcement and input into the locations and placements of the confirmation lights before installation. Both the police and signal staff should work together, in a field review, for appropriate placement of the enforcement light.



Figure 35: A confirmation light mounted to the back on an existing signal mast arm.

4.9 Protected Intersections

In urban areas, safe and comfortable intersections minimize delays, reduce conflicts, and reduce the risk of injury for *all users* in the event of a crash. Intersections include not only bicycle crossings of streets, but also crossings with driveways, alleys, sidewalks, shared use paths and other separated bike lanes. Intersections are likely to be locations where bicyclists transition into and out of separated bike lanes to other types of bikeway accommodations. These transitions should be intuitive to all users of the intersection. These intersections have been generically called protected intersections in that they are designed to keep all users protected from the different modes of transportation, while balancing delay and demand from all users as well. See [Figure 36: A conceptual layout of a protected intersection.](#) to understand how each mode has a protected right-of-way.

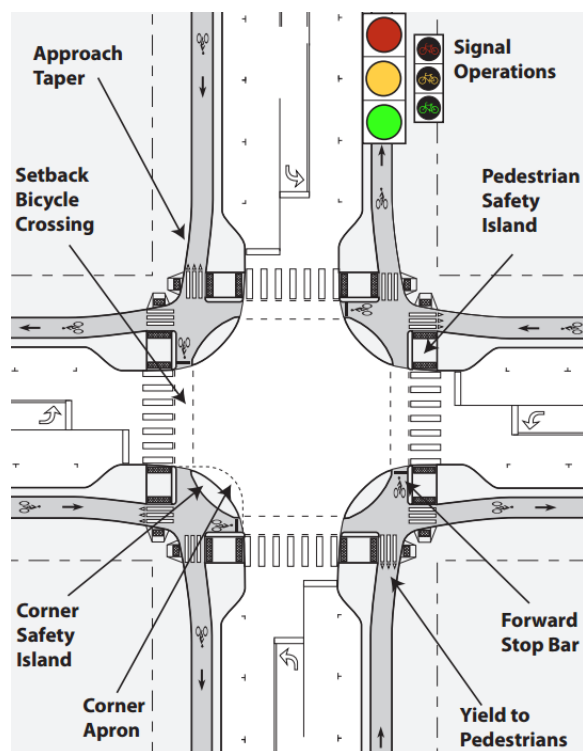


Figure 36: A conceptual layout of a protected intersection.

Bicycles, pedestrians and motor vehicles inevitably cross paths at intersections (unless their movements are grade separated). Intersections with separated bike lanes should be designed to minimize bicyclist exposure to motorized traffic and should minimize the speed differential at the points where travel movements intersect. The goal is to provide clear messages regarding right of way to all users moving through the intersection in conjunction with geometric features that result in higher compliance where users are expected to yield.

Though this idea has not been built in the US at the time of writing, this intersection is getting attention from bicycle, pedestrian, and urban design advocates.

4.10 Countdown Timers

Countdown timers are flashing timers placed on signalized intersections, and are usually installed with pedestrian indication (walk) lights, which provide the number of seconds remaining during the pedestrian phase. These devices have shown to potentially reduce crashes for both pedestrian-vehicle crashes as well as vehicle to vehicle crashes. These devices can be installed as a retroactive project onto existing signals. See [Figure 37: A pedestrian countdown timer](#). (Source: FHWA) for an example of a pedestrian countdown timer.



Figure 37: A pedestrian countdown timer. (Source: FHWA)

4.11 Leading Pedestrian Interval

With the Leading Pedestrian Interval (also known as the Advanced Walk), pedestrians are provided with a few extra seconds when the pedestrian button is pushed to begin their walk cycle before the traffic gets a green indication. Advance walk cycles have been implemented in several large metropolitan areas with great success. This lets pedestrians establish themselves in the crosswalk before cars move. This strategy can be implemented at basically no cost; the controller simply needs to be re-timed. Although re-timing traffic signals to incorporate the advance walk into the cycle signal would incur expenses for staff time, this can be a fairly low-cost strategy to improve pedestrian safety.

4.12 Curb Extensions

Curb extensions (also known as bump-outs, or bulb-outs), are an extension of the sidewalk and curbing into the traditional intersection. These extensions are effective at slowing motor vehicle speeds (especially while turning), creating pedestrian awareness, shortening the distance pedestrians needed to cross the street, and can provide clearer parking limits. Many cities have implemented these and have found them favorable.

Curb extensions can be provided at signalized and unsignalized intersections, but should be avoided on higher speed roads.

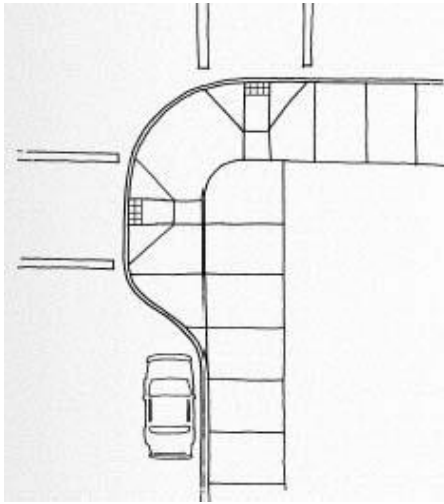


Figure 38: An illustration of a curb extension and a vehicle parked. From FHWA.

4.13 Medians/ Refuge Island

Medians and refuge islands can help with reducing crashes, lowering driver speeds, and improving pedestrian safety. These devices can be used to narrow roadway widths and thus creating an environment where drivers feel compelled to slow down. The median will also provide a place for pedestrians to safely wait and only need to cross one direction of travel at a time. Combined with curb extensions, these two treatments can drastically lower vehicle speeds (referred to as traffic calming), reduce the distance pedestrians expose themselves to traffic, and reduce the number and severity of crashes. These tools are especially effective in urban areas where low speeds are desired, and pedestrian activity is increased. Caution should be used in more high speed and rural environments where curbs and medians can be a hazard to vehicles who depart the travel way.



Figure 39: An example of a median and refuge island.

5.0 References, Links, and Resources

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